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TRAP-ML-A TWO DIMENSIONAL THERMAL RESPONSE CODE TAILORED FOR TH--ETC(U)

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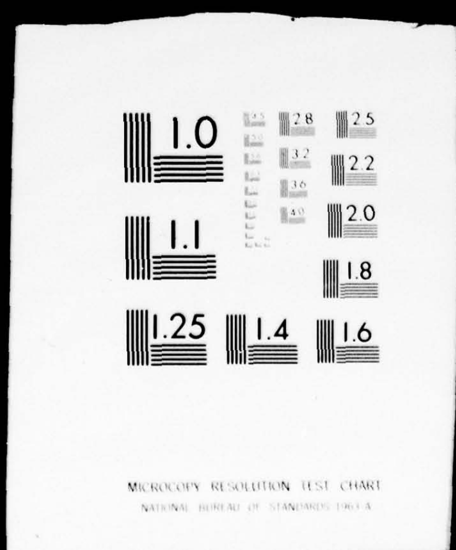

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TRAP-ML—A TWO-DIMENSIONAL THERMAL RESPONSE CODE TAILORED FOR THE DEFENSE NUCLEAR AGENCY TRI-SERVICE THERMAL RADIATION TEST FACILITY

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30 November 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

TRAP-ML is a digital computer code for calculating the two-dimensional thermal response of materials exposed to thermal radiation and wind tunnel cooling. In particular, the code can simulate the Defense Nuclear Agency Tri-Service Thermal Radiation Test Facility located at the Air Force Materials Laboratory, WPAFB, which, in turn, can simulate an in-flight nuclear encounter. (over)

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20. ABSTRACT (Continued)

The program is capable of analyzing multi-material, multi-layer samples exposed to either quartz-lamp radiation or a user-designated thermal source (as a function of both wavelength and time), with optional convective (air stream) cooling. Specific heats and thermal conductivities of the materials can be specified, in general, as functions of both temperature and radiation wavelength.

For output, the code computes the heat flow and temperature distribution throughout the finite model, and will optionally plot the temperature-time histories at layer boundaries and at both surfaces of the specimen.

PREFACE

The work was performed for the Defense Nuclear Agency (DNA) under Contract Number DNA001-78-C-0057 by Kaman Avidyne, Burlington, Mass., a division of Kaman Sciences Corporation. Captain J. M. Rafferty of DNA, and Major J. Hurst and Mr. G. Schmitt of the Air Force Materials Laboratory (AFML) at Wright-Patterson Air Force Base, Dayton, Ohio, were technical monitors. Mr. William Lee was project leader of the work performed in the Structural Mechanics Section of Kaman AviDyne headed by Mr. Emanuel S. Criscione, with technical contributions by Dr. J. R. Ruetenik and Dr. N. P. Hobbs.

Conversion factors for U.S. customary to metric (SI) units of measurement.

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
curie	giga becquerel (GBq)*	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t° f + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)**	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 X E -2
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 X E +1
rad (radiation dose absorbed)	Gray (Gy)**	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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SECTION 1
INTRODUCTION

TRAP-ML is the result of a dual effort to (1) simplify the TRAP computer code (Reference 1) for studying radiation effects on aircraft components and (2) provide an analytical predictive and correlative tool for use in the Defense Nuclear Agency (DNA) Tri-Service Thermal Radiation Test Facility located at the Air Force Materials Laboratory, WPAFB, Dayton, Ohio. The appendage "ML" on the code name indicates the special applicability of the code to the Materials Laboratory.

The DNA thermal test facility, described in detail in References 2, 3 and 4, includes a test setup consisting of a quartz lamp bank for thermal radiation and a wind tunnel providing convective cooling on material samples approximately four inches square. The samples are mounted flush with the inside surface of the wind tunnel, facing a window in the opposite tunnel wall. The sample is irradiated through this window, simulating the environment of an aircraft exposed to nuclear radiation while in flight.

The TRAP code (Thermal Response of Aircraft to Nuclear Radiation) includes the material modelling and heat transfer capabilities required for the test facility application. The solution method is based on a finite representation of the cross section by thermally thin "elements." One or more elements make up a "layer," characterized by uniform material properties and thickness, and several layers are possible. The layers make up a "segment"; several segments are allowed, introducing the possibility of two-dimensional heat flow. The heat transfer mechanisms in TRAP include radiation, convection, and conduction.

The problem with the original TRAP is that it is too general for the test facility application. For example, it also includes a nuclear source generator, atmospheric transmission and ground reflection factors, and a vulnerability assessment including an iteration on slant

range. Also, it is designed to analyze large complex aircraft structures - not laboratory samples. Clearly, these capabilities are not needed for the test facility. Nor are the stress-strain calculations needed, as the mechanical boundary conditions are not prescribed in the laboratory setup.

Certain other capabilities were required in TRAP-ML, however, which are not in the original TRAP. The quartz lamp radiation source was modelled as a function of wavelength and time and included in the program. Provision was also made for two other source options, including a point-by-point option.

While the test facility setup can be treated as a one-dimensional thermal problem, the capability to analyze two-dimensional heat flow remains. For example, the airstream does tend to "heat up" downstream, introducing a nonuniform axial temperature field. So, rather than eliminate the 2-D capability, it was retained for possible future applications.

Also, while convection and reradiation are still important, these heat transfer processes were modified slightly to better simulate the test facility. Input and output were also modified to enable the user to operate the code with less than a $60{,}000_8$ core requirement and receive temperature-versus-time plots at each surface and layer boundary of the material sample.

TRAP-ML, then, allows the user to simulate a multi-layer, multi-material sample subjected to a general radiation source (a 6000 watt tungsten lamp in particular), complete with two-dimensional heat flow, convective cooling (if needed), and reradiation, with both the source and material absorptivity specified, in general, as functions of wavelength.

With this capability, the pretest calculations can be performed which, in many cases, may reduce the number of test exposures required. And where material properties are uncertain, post-test correlation with tests involving these materials may lead to evaluations of the unknown properties.

Section 2 describes in more detail the heat transfer processes in TRAP-ML, and Section 3 documents the computer program. Section 4 includes a sample problem which is compared with a test exposure of a .032 inch aluminum sample coated with 3 mils of white polyurethane. This limited correlation indicates excellent agreement. Finally, Table 1 includes a conversion table of units (English to Metric), since the TRAP computer code (and hence, TRAP-ML) was originally formulated in the English system of units, including input and output. Program listings make up Appendices A and B.

Table 1. Conversion of units (English to metric).

Value Expressed in English Units	Multiplied By	Yields Value Expressed In Metric Units
Inch (in)	2.54	Centimeters (cm)
British Thermal Unit (BTU)	252.0	Calories (cal)
BTU/in^2	39.03	Cal/cm^2
Temperature, °R	0.5555	Temperature, °K
$BTU/in^2/°R$	70.25	$Cal/cm^2/°K$
BTU/pound mass (BTU/lb-m)	0.5555	Cal/gram
BTU/lb-m/°R	1.0	Cal/gram/°K

SECTION 2
HEAT TRANSFER MECHANISMS

2-1 RADIATION SOURCE

The primary radiation source included in the program is the quartz lamp bank consisting of 6000 watt tungsten filament bulbs. The spectral distribution and a general time history are included in a non-dimensional manner, such that the user need only specify the peak flux level to be achieved and the time of exposure before the lamps are shut off. Provision is also made for other source characteristics, or even very simple sources such as a step-on and step-off time history.

The nominal spectral distribution is based on spectrometer measurements and the point-by-point model is indicated in Figure 1. While there is some absorption of the radiation by the atmosphere, it is small since the lamps are normally located within about 2 inches of the thermal sample, and is, therefore, neglected. The distribution is considered invariant with time, although it is thought the peak intensity may shift to a higher wavelength when cool. While this is ignored in the nominal source option, the capability exists of specifying the source as a function of both wavelength and time.

The program numerically integrates the distribution between 0.2 and 5.5 microns to determine the total flux, then normalizes the entire distribution to that value as a function of 14 discrete wavelengths. If wavelengths other than the nominal 14 are specified on input, the program linearly interpolates between the inputted values to determine values for the 14 basic wavelengths. These fourteen wavelengths and their associated band widths are indicated in Table 2. When material absorptivity is specified as a function of wavelength, these 14 bands are used to numerically integrate the total absorbed radiation between 0.2 and 5.5 microns. Since all the incident radiation

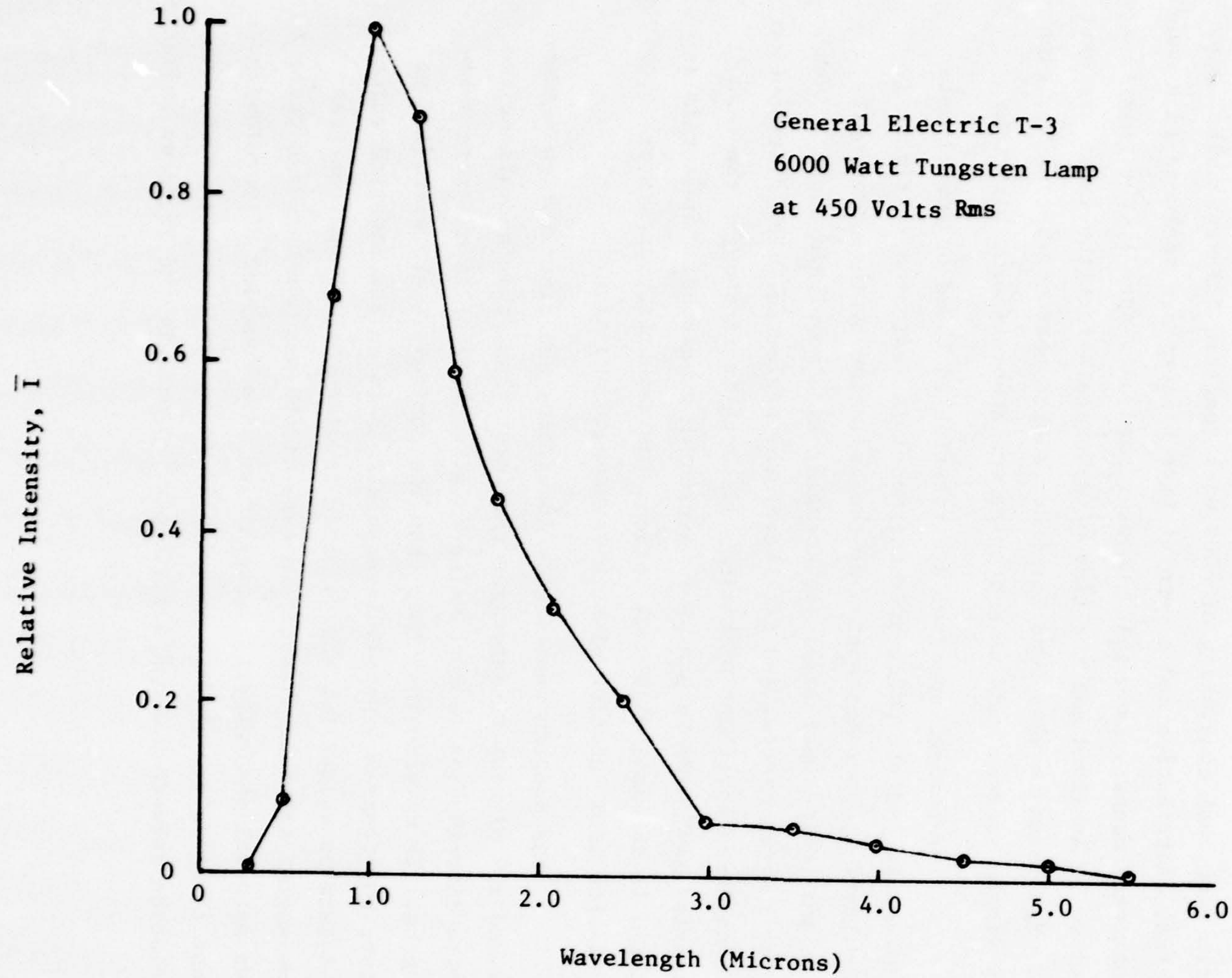

Figure 1. Spectral intensity model for nominal radiation source.

Table 2. Wavelengths used to determine absorbed flux.

Wavelength Number	Nominal Wavelength (Microns)	Wavelength Band (Microns)
1	0.288	0.2 - 0.375
2	0.5	0.375 - 0.625
3	0.75	0.625 - 0.875
4	1.0	0.875 - 1.125
5	1.25	1.125 - 1.375
6	1.5	1.375 - 1.625
7	1.75	1.625 - 1.875
8	2.0625	1.875 - 2.25
9	2.5	2.25 - 2.75
10	3.0	2.75 - 3.25
11	3.5	3.25 - 3.75
12	4.0	3.75 - 4.25
13	4.5	4.25 - 4.75
14	5.0	4.75 - 5.25

is either absorbed or reflected back into space, the incident absorbed relative intensity can be given by

$$\bar{I}^{abs} = \frac{\int_{0.2}^{5.5} \alpha(\lambda)\ \bar{I}(\lambda)\ d\lambda}{\int_{0.2}^{5.5} \bar{I}(\lambda)\ d\lambda} \tag{1}$$

where α represents the fractional absorptivity ($0 \leq \alpha \leq 1$) and λ is the wavelength.

Figure 2 indicates the nominal time-wise radiation history, where the flux has been normalized to an arbitrary value. The time history is divided into two domains:

1) The "rise" domain includes a very sharp rise in flux and then reaches a nearly steady-state value for large times. After 3.87 seconds the program assumes a constant flux.

2) The decay phase commences when the lamps are turned off and has a rapid decrease in flux until it finally is assumed to be zero at 2.85 seconds after the exposure has ended.

Regardless of when the lamps are turned off, the entire curve is normalized to a value of peak flux (q_{max}) which is specified on input. And the decay phase begins exactly with the time specified on input. The incident absorbed flux can then be given by

$$q^{abs}(t) = q_{max} \cdot \bar{I}^{abs} \cdot \bar{F}(t) \tag{2}$$

where $\bar{F}$ is the relative flux defined in Figure 2 and t represents time.

The user can also specify a simple step-on and step-off time history or a general point-by-point description. Linear interpolation is used between tabulated values. Even these distributions are normalized to the largest tabulated value so that the intensity of the radiation can be varied with a single input parameter. The entire specimen is assumed to be irradiated uniformly.

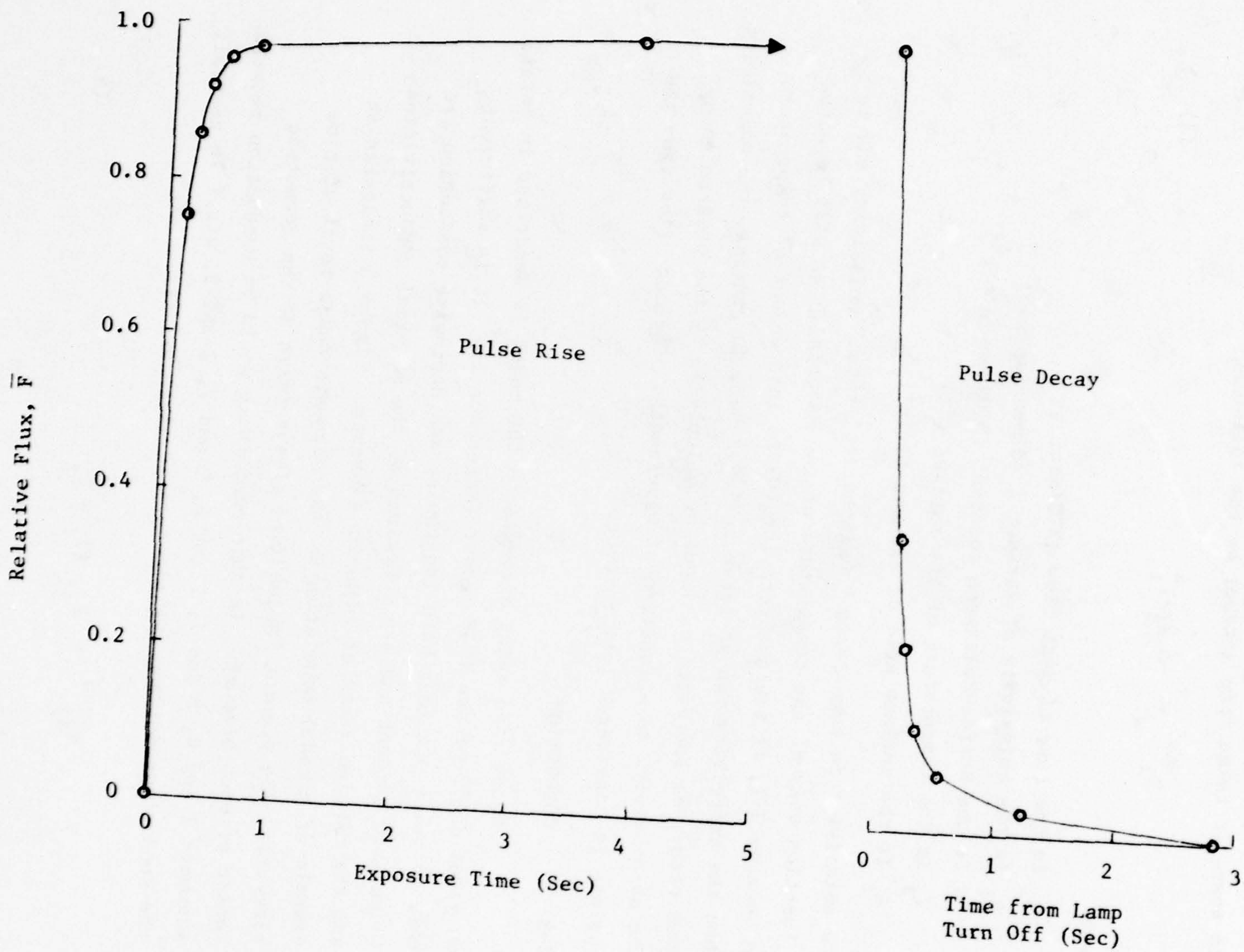

Figure 2. Time-wise exposure model of nominal radiation source.

2-2 RERADIATION

Reradiation of energy from each surface of the sample back into space is taken into account by the following:

$$q_i^{rad} = -A_i \varepsilon_i \sigma T_i^4 \tag{3}$$

where

q_i is the rate of heat flow (BTU/sec)

ε_i is the emissivity of surface i (dimensionless)

σ is the Stefan-Boltzmann constant (BTU/sec-in^2-°R^4)

T_i is the temperature of the surface (°R)

A_i is the surface area of element i (in^2)

The emissivity is considered "hemispherical total" emissivity and is a function only of the temperature of the material. As will be noted in Section 3-1, if the absorptivity (α) is independent of temperature, then the emissivity can be taken as $1-\alpha$. But, in general, the emissivity must either be specified on input or calculated by the program using the absorptivity as a function of wavelength. The heat flow from the surface is considered lost forever.

2-3 CONDUCTION

Conduction among elements in the model is described in detail on pages 86-92 of the TRAP report (Reference 1). It is sufficient here to point out that both lengthwise and depthwise conduction are taken into account and are functions of the material conductivities and the exposed areas of adjacent elements. Figure 3 indicates an example of a model consisting of two segments and a total of nine elements. The element "nodes" are always taken at the geometric center of each element. In this case there would be conduction between elements 1 and 6, 2 and 1, 2 and 6, 2 and 7, 2 and 3, etc. In general, the conduction between two elements is given by

$$q_{ij}^{cond} = \overline{K}_{ij} \, (T_i - T_j) \tag{4}$$

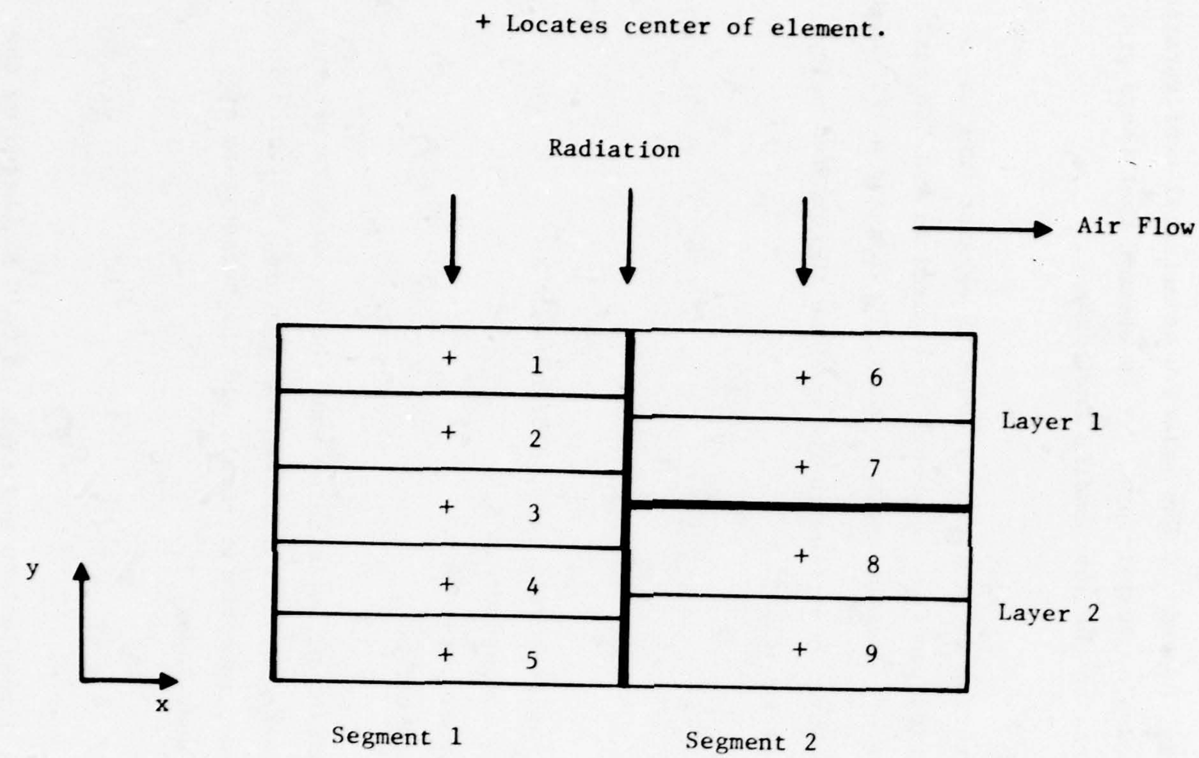

Figure 3. General two-dimensional cross-sectional model indicating elements, layers and segments.

where

$\overline{K}_{ij}$ is a conductivity factor between elements i and j, BTU/sec-°R

T is temperature, °R

As indicated earlier, $\overline{K}_{ij}$ depends on the relative geometrical configuration of elements i and j, and also temperature. It is assumed that there are no conductive heat losses to the surrounding environment.

2-4 CONVECTION

Convective cooling is provided by means of exhaust fans at the outlet end of the wind tunnel. The model is located in the "throat" of the tunnel, a region of constant cross section, 1" wide and 4 1/2" high.

The boundary-layer heat flux to the surface is computed using the Newton heat-transfer equation

$$q^{conv} = h\,(T_r - T_w)\,A \tag{5}$$

where

h is the heat transfer coefficient, BTU/in^2/sec/°R

T_r is the recovery temperature, °R

T_w is the wall temperature, °R

A is the surface area, in^2

Before discussing h, it is noted that the recovery temperature is computed with reference to the stagnation temperature, T_o (which in this case is the ambient, room temperature), and the temperature at the outer edge of the body layer, T_δ,

$$T_r = T_\delta + r\,(T_o - T_\delta) \tag{6}$$

The recovery factor is dimensionless and taken to be 0.88, based on the discussion in Reference 1.

The free-stream temperature, T_δ, can also be computed from T_o, using perfect gas relations, where a_t represents the total speed of sound in the room.

$$a_t = \sqrt{1.4\ (1716)\ T_o} = \sqrt{2402.4\ T_o} \tag{7}$$

$$T_\delta = T_o \left\{ 1 - 0.2\ (V/a_t)^2 \right\} \tag{8}$$

V is the free-stream velocity in ft/sec. The free-stream pressure, which will be needed later, can also be computed assuming a perfect gas,

$$P_\delta = P_o \left\{ 1 - 0.2\ (V/a_t)^2 \right\}^{3.5} \tag{9}$$

where P_o is the ambient (room) pressure.

This, then, leaves the heat transfer coefficient, h, to be determined. This parameter is a function of many factors, but depends primarily on the type of flow in the region of interest, namely laminar vs. turbulent. This, in turn, depends on the tunnel geometry, roughness of the surface, any leaks in the tunnel, etc. Ideally, one probably would predict laminar flow in the test facility setup, but the discussion in Reference 4 indicates the flow is actually fully developed turbulent. Due to the factors mentioned above, this is plausible and accepted.

Based on turbulent flow, then, the Colburn equation (Reference 5) is used to take into account dependence of h on wall temperature and air-stream velocity (two velocities are possible, depending on whether one or two blowers is used). This requires either knowledge of the effective origin of the turbulent flow, or some empirical information regarding the value of h for a particular case. Reference 4 provided the latter, where an average value of 1.67×10^{-4} BTU/sec/in^2/°R was determined for an air flow of 793 ft/sec. The effective origin (x_{eff}) was then back figured to be 1.15 inches.

The Colburn equation and other necessary relations are presented below. The user is referred to Reference 1 for a more complete discussion.

$$h = \frac{0.026 \cdot k \cdot R_{e_{eff}}^{.8}}{x_{eff}} \tag{10}$$

where

$$k = \left[1.0 - 8.89\ (10^{-6})\ T' + 3.58\ (10^{-8})\ T'^{2}\right] \cdot \left[2\ (10^{-8})\ T'^{1.5}/(T' + 201.6)\right] \tag{11}$$

$$R_{e_{eff}} = \frac{R_e \cdot V \cdot x_{eff}}{12} \tag{12}$$

$$R_e = 3.7\ (10^{6})\ P_\delta\ (T' + 198.6)/(T')^{2.5} \tag{13}$$

$$T' = 0.5\ (T_W + T_\delta) + 0.22\ (T_r - T_\delta) \tag{14}$$

The program also provides the user with the optional capability of specifying the heat transfer coefficient, h, which allows him more direct control over that parameter.

2-5 TEMPERATURE CHANGE

The computer program combines the results of all the heat transfer mechanisms at each instant of time for each element. The temperature change can then be calculated for the finite time interval according to

$$\Delta T = \frac{\Delta t}{\rho A c_p}\ q \tag{15}$$

where

ΔT is the temperature rise, °R

Δt is the time interval, sec

ρ is the element density, lbs/in^3

c_p is the specific heat of the material, BTU/lb-°R

A is the cross-sectional area (volume) of the element, in^2

q is the net heat flow into the element, BTU/sec.

SECTION 3
COMPUTER PROGRAM DESCRIPTION

3-1 PROGRAM OPERATION

The TRAP-ML program was written in FORTRAN IV and developed on the Control Data Corporation (CDC) 6600 computer. The program requires card input, which is described in Section 3-2, and produces time history response output, the subject of Section 3-3. The program also has the capability to produce a plot file of temperatures versus time. This data file then serves as input to a second program, APLOT, which produces paper plots. This second program requires no card input of its own.

To execute and also generate plots, then, requires the execution of both TRAP-ML and APLOT back to back. The primary reason for separating the two codes was to enable the user to run with less than a $60{,}000_8$ cell core requirement. This makes it possible to operate the code from remote terminal under current WPAFB restrictions. A typical job control setup is shown in Table 3.

The routines for both programs are listed in Table 4. The basic plot routines are included in the APLOT package, rather than calling on system routines, so that the program is less dependent on one particular computer.

TRAP-ML requires approximately $53{,}000_8$ to load and execute. Logical files TAPE1 and TAPE6 are used for input and output, respectively. TAPE5 is used internally to store the input data subsequent to reading the data into the computer. The plot information is written to file TAPE8 and is automatically rewound prior to and upon completion of job. More than one case can be run during a job execution, in which case the plot output for each case represents a separate file on TAPE8. Approximately 8 cp seconds are required to compile TRAP-ML using "OPT=1" and "R=2" options.

Table 3. Typical job control sequence.

Job Control Cards	Comments
JOB CARD......	
MAP,PART	
ATTACH,A,TRAPML......	Attach and execute TRAP-ML
A.	binary file
ATTACH,B,APLOT......	Attach and execute APLOT
B.	*if* plots are desired.
ROUTE,PLOT,.....	Direct the plot file to remote terminal
EXIT.	
7/8/9	
input data for TRAPML	
6/7/8/9	

Table 4. TRAP-ML and APLOT routines.

TRAP-ML	APLOT
TRAPML	APLOT
BLOCK DATA	FIRST
CONVEC	KALINE
DTEMP	KALE
FLUX	KANUM
INTIZ	KASYM
RPLOT	KAVANS
RPRINT	KAXIS
SETUP	
SPECT	
TIN	
TSTEP	
XHEAT	

Program APLOT only requires the file TAPE8 for input, but does generate output on TAPE6. The program also ultilizes file TAPE40 for internal purposes. If on-line plots are requested, then the file PLOTS represents the resultant plot file, ready to be directed to a plotter.

APLOT requires approximately $50{,}000_8$ cells of memory to load and execute. Compilation requires only about four cp seconds.

Execution times will depend on the size of the model, the time interval required, and the duration of the response requested, but generally program APLOT will execute for only a small fraction of the time used by TRAP-ML. The example problem discussed in Section 3-4 required about 40 cp seconds for both programs.

3-2 PROGRAM INPUT

TRAP-ML looks for BATCH input on file INPUT. The input data are specified in groups, where each group begins on a separate card. More than one card may be required for a group, however. The variable type and format corresponding to each data group is given in parentheses in the input instruction and is always in fields of 12. For convenience, floating point numbers can be left justified in the field as long as the exponent is right justified. Also, zero values can be replaced by a blank field. Columns 73 through 80 are not used for data and can be used for card identification or other purposes.

All input parameters, where appropriate, should be compared with the maximum dimensions provided for in the program, as delineated in Table 5. This is very important since the program does not attempt to check the input for all such violations. In Table 5, the input parameters are delineated with an asterisk (*) preceding the variable name.

The specific instructions for input are contained in Table 6. The remainder of this section will attempt to amplify on those instructions and provide insight into the applicability and limitations of the program.

Table 5. Description of variables which determine program dimensions.

VARIABLE	LIMIT	DESCRIPTION
*NAT	10	Number of temperatures at which absorptivity is given.
NCONDC	122	Number of conduction connections between elements.
*NCPT	10	Number of temperatures at which specific heat is given.
*NCT	10	Number of temperatures at which conductivity is given.
NEL#	75	Total number of elements.
NFALL	8	Number of points at which the relative flux is specified versus time in the decay phase.
*NFLUX	15	Number of points describing thermal flux time history.
NLAY	5	Number of layers in segment.
NMAT	9	Number of different materials.
NRISE	8	Number of points at which the relative flux is specified versus time in the "rise" phase.
*NSEG	3	Number of segments.
*NTSPEC	3	Number of times at which spectral distribution of radiation source is specified.
NWL	14	Number of wavelength bands used to describe radiation source in calculations.
*NWLA	10	Number of wavelengths at which absorptivity is specified for new material.
*NWLI	50	Number of wavelengths used to describe spectral distribution.

NOTES:

* - Variable is specified on input.

\# - Dimension also limited in subroutine SETUP by a fixed point number before statement number 23.

Table 6. TRAP-ML input.

Group 1: (40A2) (ID(I), I=1, 40)

Title card - free field. (ID)

Group 2: (2I12) INOUT, IPLOT

Program output-option code: (INOUT)
- 0, do not print input data
- 1, print input data

Plot code (IPLOT)
- 0, do not generate plots of temperature vs. time
- 1, do generate plots of temperature vs. time

Group 3: (I12) NSEG

Number of segments. ($1 \leq NSEG \leq 3$)

Group 4: (2F12.1) XSEG(IS), YSEG(IS)

x-coordinate of end of segment, in (XSEG)
y-coordinate of end of segment, in (YSEG)

Note - See Figure 3 for definition of coordinates.

Repeat Group 4 for IS=1, NSEG+1

Groups 5-7 provide data for each segment, IS, and are to be repeated for IS=1, NSEG

Group 5: (I12) NLAY(IS)

Number of layers in segment ($1 \leq NLAY(IS) \leq 5$).

Groups 6-7 provide data for each layer, IL, and are to be repeated for IL=1, NLAY(IS)

Group 6: (F12.1) TLAY (IS,IL)

Thickness of layer, in. [TLAY(IS,IL)]

Group 7: (2I12) KMAT (IS,IL), NELL(IS,IL)

Code defining material of layer: (KMAT (IS,IL))
- 1, Aluminum, 2024-T3
- 2, Aluminum, 7075-T6
- 3, Magnesium, AZ31B-H24
- 4, Titanium, Ti-8Mn

Table 6. (Continued)

If materials other than those listed above are used, they should be assigned numbers which are consecutive beginning with 5. Material properties for the added materials are called for in Groups 8-21

Number of elements in layer. (NELL(IS,IL))

Groups 8-22 provide material properties data for each added material, NM, and should be repeated until all added materials have been completed. If there are no added materials, skip to Group 23.

Group 8: (I12) MCOR(NM)

Number of material to which new material partially corresponds. This number may be any number lower than the number of the new material for which data are now being supplied. Use of a corresponding material allows the analyst to skip reading in material properties which are the same as those of the corresponding material. If this number is read in as zero, all material properties for the new material must be supplied, starting with Group 10 and ending with Group 22. (MCOR(NM))

If MCOR = 0, skip to Group 10.

Group 9: (I12) KCH

Code indicating material property to be changed:

- 1, absorptivity
- 2, conductivity
- 4, specific heat
- 5, melting temperature
- 6, heat of fusion
- 11, density

Under this mode of input, a change card is read in for each property to be changed, followed by data for the specified material property. Group 22 terminates this sequence. (KCH)

Groups 10-13 provide absorptivity data for the new material, if required. (MCOR = 0 or KCH = 1)

Group 10: (I12) NAT(NM)

Number of temperatures at which absorptivity is given NAT(NM))

Table 6. (Continued)

Groups 11-13 provide data for one temperature, NT, and are to be repeated for NT = 1, NAT(NM).

Group 11: (2F12.1) TALF(NT,NM), EMI(NT,NM)

Temperature at which absorptivity is given, °R (TALF(NT,NM))

Emissivity at specified temperature, dimensionless (EMI(NT,NM)) (Omit if integration of absorptivity by program is desired in order to obtain emissivity)

Group 12: (I12) NWLA

Number of wavelengths at which absorptivity is specified (NWLA)

Group 13: (2F12.1) WL(NW,NT), ALF(NW,NT)

Wavelength at which absorptivity is given, microns* (WL(NW,NT))

Absorptivity, dimensionless (ALF(NW,NT))

Repeat Group 13 for NW = 1, NWLA.

Groups 14-16 provide conductivity data for the new material, if required (MCOR = 0 or KCH = 2)

Group 14: (I12) KLD(NM)

Code of conductivities: (KLD(KM))
1, lengthwise and depthwise conductivities are the same
2, lengthwise and depthwise conductivities are different

Group 15: (I12) NCT(NM)

Number of temperatures at which conductivity is given (NCT(NM))

Group 16: (3F12.1) TCOND(NT,NM), CONDL(NT,NM), CONDD(NT,NM)

Temperature at which conductivity is given, °R (TCOND(NT,NM)

Lengthwise conductivity of material, BTU/in-sec-°R (CONDL(NT,NM))

*If emissivity has been specified in Group 11, only wavelengths from 0.2 to 5.5 microns must be covered. If emissivity is to be found by integration of absorptivity, wavelengths from 0.2 to about 250 microns must be covered.

Table 6. (Continued)

Depthwise conductivity of material (Omit if KLD(NM) = 1), BTU/in-sec-°R (CONDD(NT,NM))

Repeat Group 16 for NT = 1, NCT(NM)

Groups 17-18 provide specific heat data for the new material, if required (MCOR = 0 or KCH = 4)

Group 17: (I12) NCPT(NM)

Number of temperatures at which specific heat is given (NCPT(NM))

Group 18: (2F12.1) TCP(NT,NM), CPM(NT,NM)

Temperature at which specific heat is given, °R (TCP(NT,NM))

Specific heat of material, BTU/lb-°R(CPM(NT,NM))

Repeat Group 18 for NT = 1, NCPT(NM)

Group 19 provides melting temperature data for the new material if required (MCOR = 0 or KCH = 5)

Group 19: (F12.1)

Melting temperature, °R (TMELT(NM))

If the melting temperature is changed, usually all of the material properties will have to be changed. The reason for this is as follows: the me ting temperature for each material for which data are pro ided in the program is the same as the maximum tempera ure for the material property data. Suppose that th melting temperature is increased. Unless the other ma erial properties are also changed, the melting temperatu will be above the maximum temperature at which material p perties are available. The program will then produce a error stop.

Group 20 provides heat of fusion data for the w material, if required (MCOR = 0 or KCH = 6)

Group 20: (F12.1) HOF(NM)

Heat of fusion of material, BT b (HOF(NM))

Table 6. (Continued)

Group 21 provides density data for the new material, if required (MCOR = 0 or KCH = 11)

Group 21: (F12.1) RHOM(NM)

Density of material, lbs/in^3 (RHOM(NM))

Group 22: Blank card. Is required for each new material NM, either at the completion of Groups 10-21 for MCOR(NM) = 0, or at the completion of the sets of data beginning with Group 9 for NCOR(NM)70.

Group 23: (4F12.1) VEL, PO, TAM, HCONO

Velocity of free-stream flow, ft/sec (VEL)

Ambient (room) pressure, psi (PO)

Ambient (room) temperature, degrees F (TAM)

Convective heat transfer coefficient, BTU/in^2-sec-°R (HCONO)

Note - Program computes coefficients for each segment if HCONO=0.0.

Group 24: (I12) NOPT

Code designating thermal flux time history (NOPT)
- 1, 6000 watt tungsten source (Figure 2)
- 2, Step load.
- 3, Arbitrary point-by-point description.

Group 25: (F12.1) QDMAX

Maximum flux achieved, BTU/in^2-sec (QDMAX)

If NOPT=3, skip Group 26

Group 26: (F12.1) TCUT

Time at which thermal source is cut off, sec. (TCUT)

If NOPT<3, skip Groups 27-28.

Group 27: (I12) NFLUX

Number of points describing thermal flux time history. First point must include time=0. ($2 \leq NFLUX \leq 15$)

Table 6. (Continued)

Group 28: (2F12.1) TFLUX(I), FLUXT(I)

Time, sec (TFLUX(I))

Relative flux corresponding to TFLUX, BTU/in^2/sec. Magnitude of flux is adjusted to QDMAX. (FLUXT(I))

Repeat Group 28 for I = 1, NFLUX

Group 29: (2I12) NWLI, NTSPEC

Code designating spectral distribution of flux (NWLI)
- 0, 6000 watt tungsten characteristics for all times (Figure 1).
- >0, number of wavelengths used to describe distribution ($2 \leq NWLI \leq 50$).

Number of times at which spectral distribution is specified. Assumed to be 1 if NWLI=0. ($1 \leq NTSPEC \leq 3$).

If NWLI=0 or NTSPEC=1, skip Group 30.

Group 30: (6F12.1) (TSPEC(I), I=1, NTSPEC)

Times at which spectral distribution is specified. First time must be 0.0. (TPSEC)

If NWLI=0, skip Group 31.

Group 31: (2F12.1) (WAVE(J,I), QR(J,I))

Wavelength at which flux is specified. First wavelength must be 0.2 microns; the last must be 5.5. (WAVE)

Relative flux corresponding to WAVE, BTU/in^2/sec. Only relative magnitudes are important. (QR)

Repeat Group 31 for J=1, NWLI, then repeat that sequence for I=1, NTSPEC.

Group 32: (3F12.1) DELTIM, TSTOP, PRINT

Integration time interval (if read in as 0.0, program will determine time interval required for stability), sec (DELTIM)

Time at which computations are to stop, sec (TSTOP)

Number of time intervals between printouts (0.0 will give no printout), dimensionless (PRINT)

Table 6. (Concluded)

<u>To execute another problem, repeat Groups 1-32.</u>

Group 33: (A3) IEND

To terminate job, place "END" in columns 1-3. (IEND)

TRAP-ML has the capability to assemble a two-dimensional heat transfer model of a particular material specimen. This implies that the specimen and the thermal loads are uniform in one coordinate direction - defined here to be the z direction. The x-coordinate direction is defined as in the direction of the air flow, and y is defined to be from the unexposed surface through the cross section toward the exposed surface (see Figure 3).

The model consists of segments, layers and elements, where elements are the basic "building blocks" and must be thermally "thin"; i.e., the temperature gradient is accurate only to the extent that enough elements are included in the model. Geometrically, the elements are horizontal slices of the cross section of constant thickness. Layers consist of a set of elements, all of which exhibit identical material properties. The model can contain up to five layers in the cross section per segment. The segment is defined as a depthwise set of layers representing a rectangular portion of the cross section. Elements, layers, and segments all have constant thickness. If only one segment is included in the model, the program is, by definition, reduced to a one-dimensional analysis. It is expected that only one segment will be used to model the test specimens.

In the general model indicated in Figure 3, segment 1 has only one layer and five elements. Segment 2 consists of two layers, each having two elements.

Now for the input instructions in Table 6. Group 1 represents a free-field case descriptor which appears as a title in the output. The first 40 columns will also appear on plots if requested. It should be pointed out that data groups 1 through 32 are repeated for as many cases as the user desires.

Group 2 defines the output options. By selecting INOUT=1, the output is reduced somewhat and the user still gets a raw data listing at the beginning of the output. The plots which are generated if IPLOT=1 give temperature at both surfaces and at each layer boundary versus time.

Group 4 defines the location and size of each segment by specifying the lower, left-hand and right-hand coordinates of each segment as defined in Figure 3. The coordinate origin can be located anywhere - one might just as well start with (0., 0.) for the first segment as not. Groups 5 and 6 define the layers.

Group 7 introduces the material properties. If materials or material properties other than those associated with the four materials indicated are desired, the user can accomplish this by calling for one or more additional materials. The first new material is number 5, the second number 6, etc. The properties corresponding to the four built-in metal alloys are indicated in Table 7 and Figures 4 and 5. In this regard, it will be noted that the selection of these four materials was arbitrary and the user is referred to Reference 1 for a complete discussion of property specification. It should be noted, for example, that the absorptivities specified for materials 1-4 are all 0.5 for an unpainted condition. If the user wants to specify a different absorptivity, he would need to call for a new material and proceed with the input.

Also in Group 7 the user must decide on the number of elements per layer. The program automically divides each layer into elements of equal thickness, depending on the number (NELL) specified. In general, thicker layers with lower conductivities will require more elements. One guideline, other than checking the resulting output to see that the temperature gradient is not too large, is to check the Δt calculation (see the discussion of Δt in Group 32). Here it makes some sense to end up with a Δt requirement more or less the same for all elements. At least two elements per layer are recommended so that a good estimate of temperature can be made at the boundary between layers and at the surface.

Group 32 requires the selection of a Δt to be used in the numerical integrations. This number must be small enough to give a stable solution. If $\Delta t=0.0$ is specified, the program will compute a Δt associated with each element and then select the smallest of these.

Table 7. Material properties in TRAP-ML.

Property \ Material	Aluminum 2024-T3	Aluminum 7075-T6	Magnesium AZ31B-H24	Titanium Ti-8Mn
Absorptivity	0.5	0.5	0.5	0.5
Emissivity	0.5	0.5	0.5	0.5
Heat of Fusion (BTU/lb)	170.	170.	158.	188.
Density (lb/in^3)	0.100	0.101	0.064	0.171
Melt Temp. (°R)	1680.	1680.	1662.	3495.

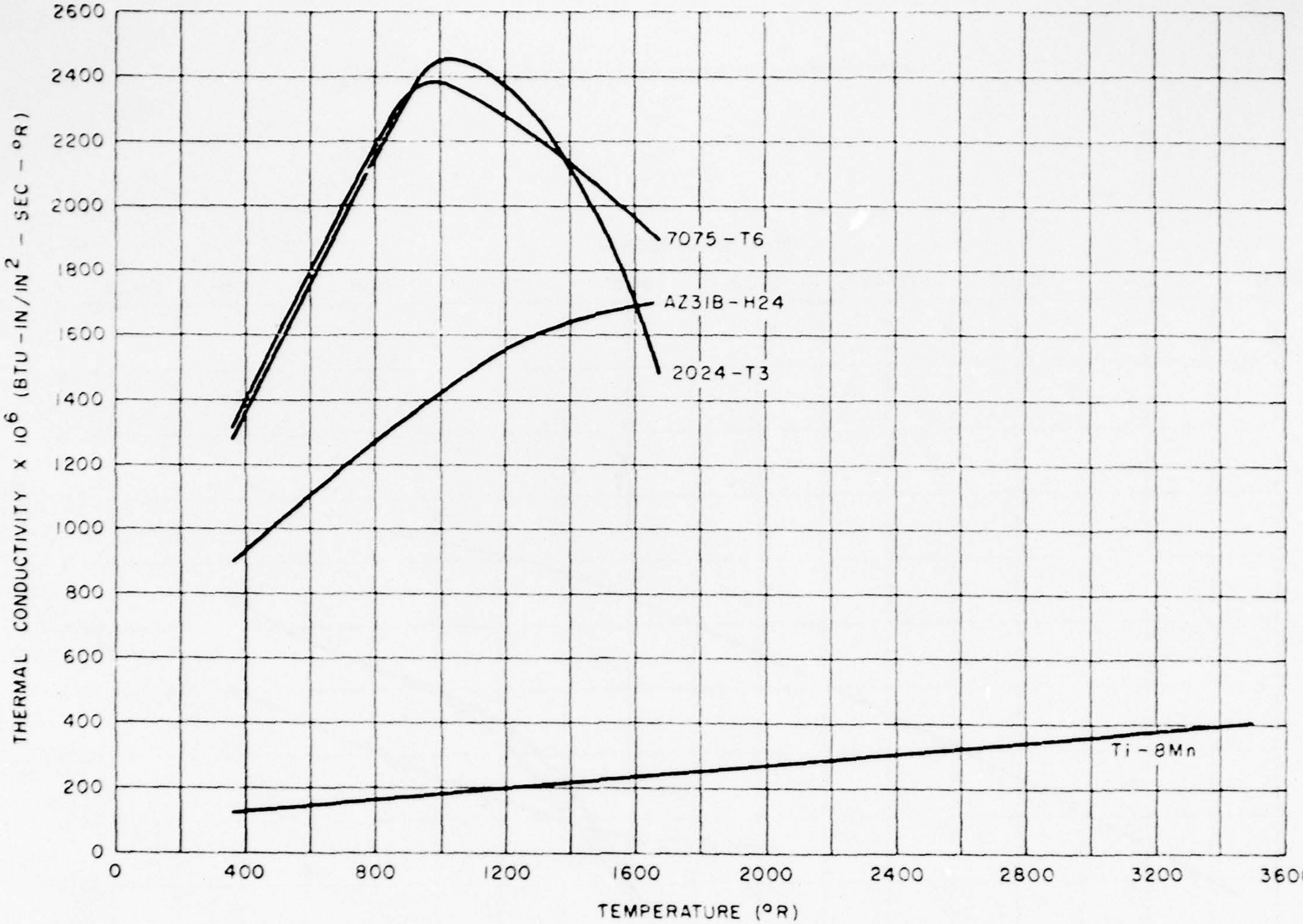

Figure 4. Thermal conductivity versus temperature.

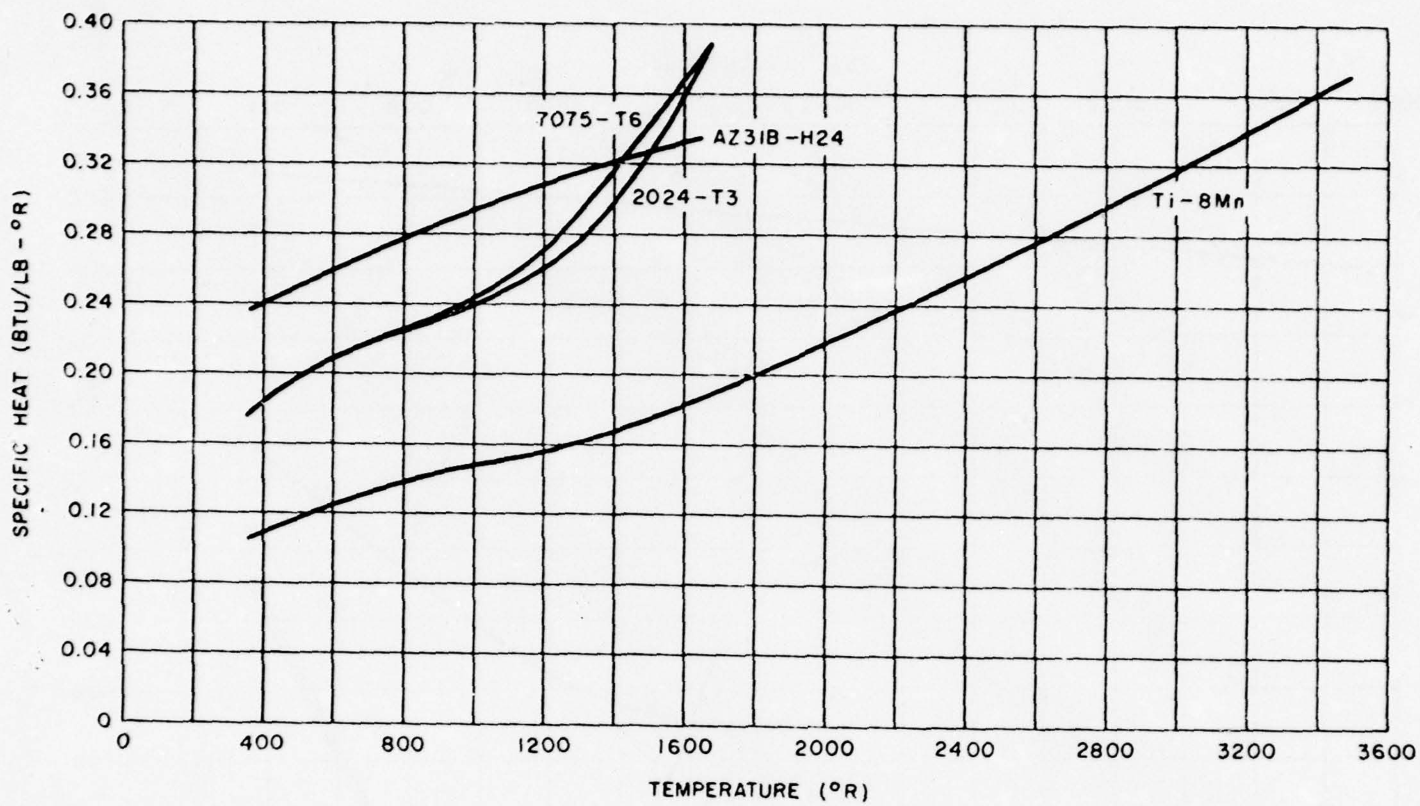

Figure 5. Specific heat versus temperature.

The user is referred to Reference 1 for a complete discussion of the formulation, but the resultant formula used is the following:

$$\Delta t_i = \frac{0.8\ \rho_i\ A_i\ C_{p_i}}{\sum_j \bar{K}_{ij}} \tag{16}$$

where the summation on j extends over all elements which touch element i. These numbers are then printed out for the user's information.

Groups 8 through 22 permit the user to specify new material properties. Note that if the new material (called for in Group 7) does not have totally different properties from one of the four basic material options, then only those properties that change need be specified. For example, if one were to specify the absorptivities for 7075-T6 Al, then MCOR (Group 8) would be 2 and KCH (Group 9) would be 1. The absorptivities would be specified in Groups 10-13.

With regard to melt temperature (Group 19), the program treats the melting of an element by eliminating it from the solution. The next element then becomes exposed to the radiation source, with the implicit assumption that the melting always proceeds from the exposed surface toward the opposite surface, element by element. The output reflects this event by setting the temperature of a melted layer to 0.0 in the printed output, and a small vertical arrow indicates the event on the plotted output.

3-3 PROGRAM OUTPUT

TRAP-ML output consists of three logically distinct sections. The first output is a card image listing of the entire input deck, exactly as it is read in, except that the cards are numbered. The second section describes the input data (if INOUT=1) in terms of its meaning in the program.

The third section is the time-history response output. At each printout time the following values are printed: time, incident flux, incident fluence, and a table of (1) temperatures and (2) a

breakdown of heat flow factors for each element. Figure 6 represents typical time-history output for three consecutive printouts.

If plots are requested (IPLOT=1), the program also stores between 100 and 200 sets of temperatures (evenly spaced in time) for both surfaces of the model and for each layer division for segment 1, or for segment 3 if there are 3 segments in the model. Linear interpolation/extrapolation is used to estimate these temperatures based on the available values at the center of each element. Each curve plotted is identified by a unique symbol. These symbols are defined in Table 8. The final two lines of printed output indicate the number of data points per curve and the number of curves written to disk file.

Error messages are largely self-explanatory, although the linear interpolution routine (INT1Z) only indicates a code number indicating the source of a problem if a variable exceeds the limit of the table. Table 9 identifies the routine corresponding to the error code.

Program APLOT generates a list of the data plotted and indicates the completion of each graph as it is actually generated.

```
TIME, SEC =      .158437E+01
  INCIDENT FLUX, BTU/IN**2/SEC =      .816905E+00
  INCIDENT FLUENCE, BTU/IN**2  =      .119566E+01

  SEGMENT  ELEMENT TEMPERATURE            H E A T     F L O W ,     B T U / S E C
  NUMBER   NUMBER   DEGREES R     ABSORPTION  RERADIATION   CONVECTION    CONDUCTION       NET
     1        1      .9467E+03     .7908E+00   -.8184E-02   -.2627E+00   -.5126E+00    .7266E-02
     1        2      .9185E+03                                            .7476E-02    .7476E-02
     1        3      .8866E+03                                            .7681E-02    .7681E-02
     1        4      .8593E+03                                            .7882E-02    .7882E-02
     1        5      .8304E+03                                            .8079E-02    .8079E-02
     1        6      .8157E+03                                            .2392E+00    .2392E+00
     1        7      .8153E+03                 -.2943E-02                 .2423E+00    .2394E+00

TIME, SEC =      .198046E+01
  INCIDENT FLUX, BTU/IN**2/SEC =      .819855E+00
  INCIDENT FLUENCE, BTU/IN**2  =      .151783E+01

  SEGMENT  ELEMENT TEMPERATURE            H E A T     F L O W ,     B T U / S E C
  NUMBER   NUMBER   DEGREES R     ABSORPTION  RERADIATION   CONVECTION    CONDUCTION       NET
     1        1      .1005E+04     .7936E+00   -.1030E-01   -.2909E+00   -.4857E+00    .6764E-02
     1        2      .9763E+03                                            .6951E-02    .6951E-02
     1        3      .9480E+03                                            .7135E-02    .7135E-02
     1        4      .9201E+03                                            .7316E-02    .7316E-02
     1        5      .8927E+03                                            .7492E-02    .7492E-02
     1        6      .8788E+03                                            .2264E+00    .2264E+00
     1        7      .8784E+03                 -.3967E-02                 .2304E+00    .2265E+00

TIME, SEC =      .237655E+01
  INCIDENT FLUX, BTU/IN**2/SEC =      .101594E+00
  INCIDENT FLUENCE, BTU/IN**2  =      .166297E+01

  SEGMENT  ELEMENT TEMPERATURE            H E A T     F L O W ,     B T U / S E C
  NUMBER   NUMBER   DEGREES R     ABSORPTION  RERADIATION   CONVECTION    CONDUCTION       NET
     1        1      .8663E+03     .9834E-01   -.5694E-02   -.2191E+00    .1207E+00   -.5781E-02
     1        2      .8734E+03                                           -.5115E-02   -.5115E-02
     1        3      .8803E+03                                           -.4299E-02   -.4299E-02
     1        4      .8868E+03                                           -.3365E-02   -.3365E-02
     1        5      .8932E+03                                           -.2361E-02   -.2361E-02
     1        6      .8964E+03                                           -.5515E-01   -.5515E-01
     1        7      .8965E+03                 -.4307E-02                -.5038E-01   -.5469E-01
```

Figure 6. Time-history output for sample problem.

Table 8. Plot symbols used to identify plot curves.

Curve Number (front face first-back face last)	Plot Symbol
1 (front face)	□
2	△
3	×
4	◇
5	+
6	○

Note - A vertical arrow (↑) indicates the time at which the element melted.

Table 9. Error codes from INT1Z.

Error Code	Subroutine which called INT1Z	Location Code #
1	SPECT	300^{-2}
2	FLUX	300
3	SPECT	700^{-1}
4	SETUP	228^{-3}
5	TSTEP	12
6	TSTEP	13
7	DTEMP	7
8	DTEMP	10
9	XHEAT	62
10	XHEAT	83
11	DTEMP	25
12	SETUP	117^{-1}
13	TSTEP	12^{-4}
14	XHEAT	42

#The location code is read as follows: a code $S^{\pm n}$ is interpreted as FORTRAN statement number S plus or minus n cards.

SECTION 4
SAMPLE PROBLEM AND COMPARISON WITH EXPERIMENT

The sample problem described in this section is designed to (a) provide the user with a check case for exercising the code, (b) provide an example of input data preparation, and (c) make a limited comparison with experimental results. The example case selected is based on an experiment performed at the DNA test facility and documented in Reference 4. A four inch sample of 2024-T3 aluminum substrate .032 inches thick was coated with .003 inch of white polyurethane and subjected to a 793 ft/sec wind tunnel flow and a two second pulse from the quartz lamp bank.

The input data for TRAP-ML is indicated in Figure 7. Although the data corresponds to the test data as closely as possible, the documentation was not totally complete. Figure 8 represents the plot generated by APLOT of three temperature-time histories: (1) the exposed surface, which obtained a peak temperature of 1019°R, (2) the division between coating and substrate, and (3) the unexposed surface (backface), which obtained a peak temperature of 900°R. The last two curves fall virtually one on top of the other due to the relatively high conductivity of the aluminum. Remember, the plot symbol codes are tabulated in Table 8. The printed output in the vicinity of where peak front-face temperatures were computed can be found in Figure 6.

Figure 9 compares the backface temperature with that presented in Figure 26 of Reference 4. Also shown are the results of the ASTHMA code from Reference 4. In general, TRAP-ML seems to predict the temperature response well - its only shortcoming is a failure in this case to predict as large a peak temperature. This minor deviance could easily be explained by any number of uncertainties in the data, e.g., the exact shape of the radiation pulse time history.

```
WHITE POLYURETHANE OVER .032 IN. 2024-T3   SAMPLE PROBLEM.
              1            1
              1
0.             0.
4.             0.
              2
.003
              5            5
.032
              1            2
              0
              2
460.           .758
              2
.2             .242
5.5            .242
4000.          .758
              2
.2             .242
5.5            .242
              1
              2
0.             2.54      E-6
4000.          2.54      E-6
              2
0.             .41
4000.          .41
1200.
50.
.0502

793.           14.3         75.          0.
              1
.82
2.
              0            0
0.             8.           500.
END
```

Figure 7. Sample problem input data.

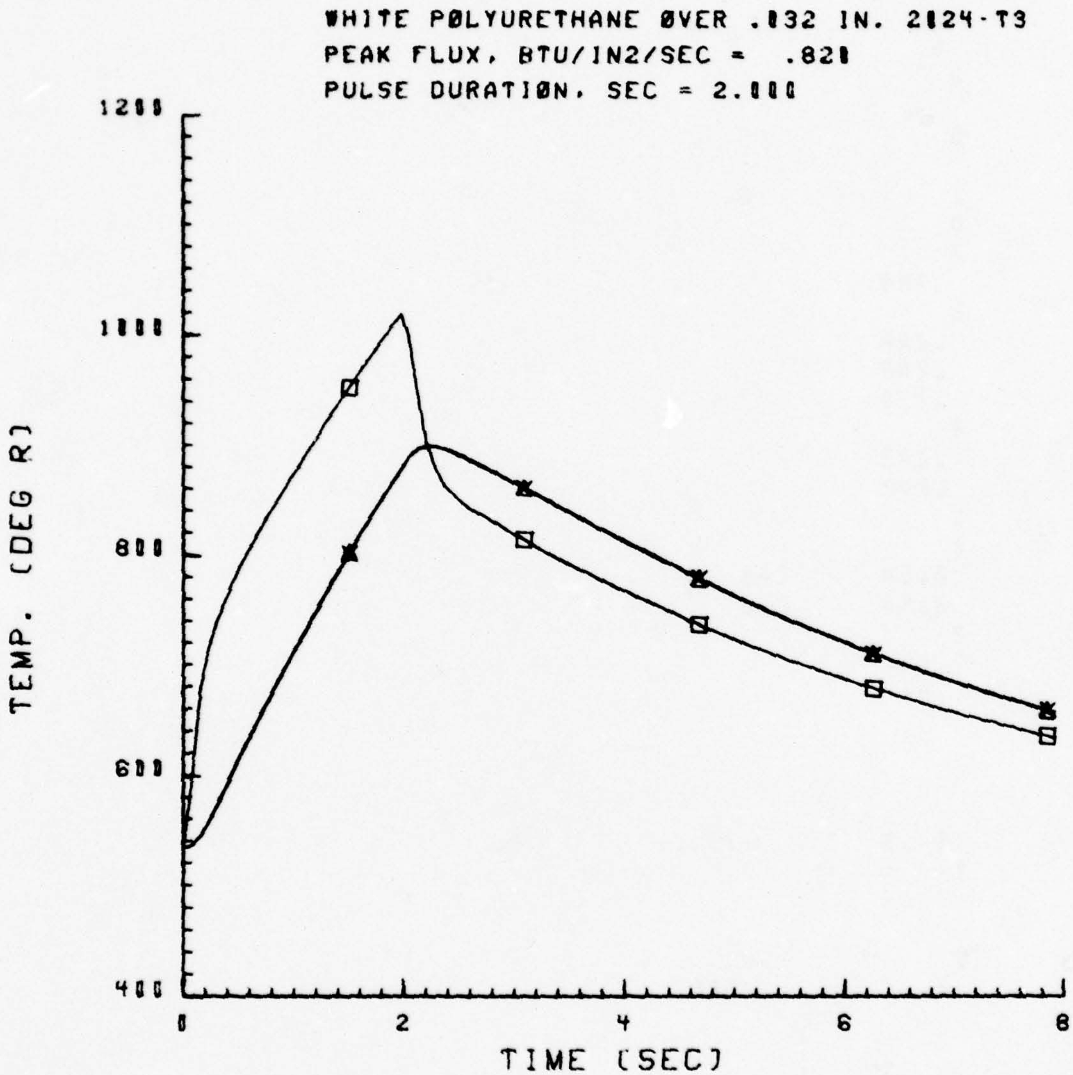

Figure 8. Computer-generated sample plot.

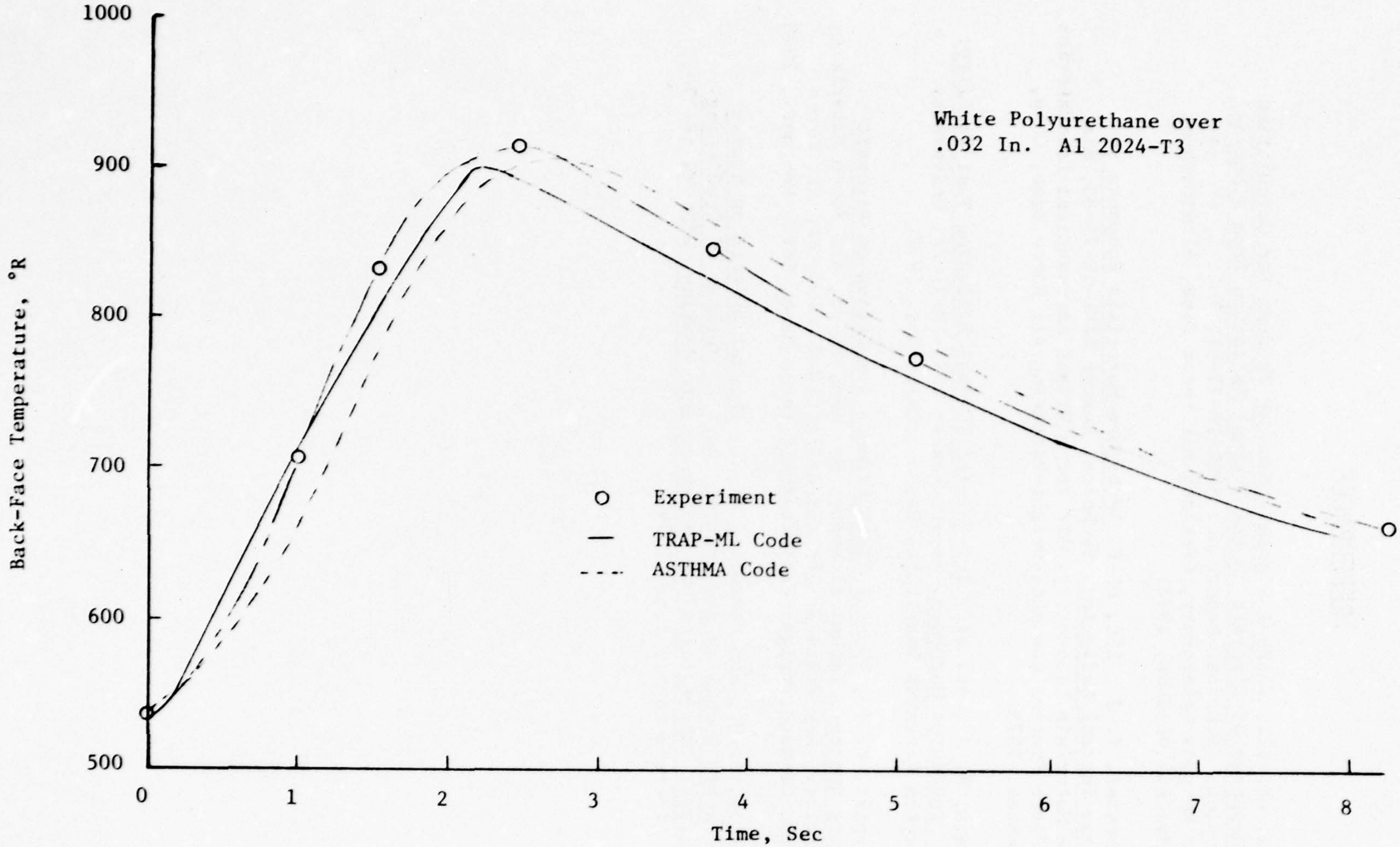

Figure 9. Comparison of TRAP-ML predictions to experiment.

REFERENCES

1. Hobbs, et. al., TRAP--A Digital Computer Program for Calculating the Response of Aircraft to the Thermal Radiation From A Nuclear Explosion, Technical Report No. AFWL-TR-71-61, Vol. 1, the Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, October, 1972.

2. Vandersaar, F. J., 1Lt, USAF, Aerospace Materials Response to Intense Thermal Radiation, Technical Report AFML-TR-75-83, Air Force Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, September, 1975.

3. Servais, R. A., et. al., Tri-Service Thermal Radiation Test Facility: Test Procedures Handbook, Report Number UDRI-TR-77-28, University of Dayton Research Institute, Dayton, Ohio, May, 1977.

4. Moscynski, M. J., Thermal Flash Effects Simulation on Aircraft Coating Systems, Technical Report No. AFML-TR-78, Air Force Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, February, 1978.

5. Blessing, A. H., and Hanawalt, A. J., Thermal Effects on Static Aeroelastic Stability and Control, Part I, Methods of Predicting Structural Temperatures Due to Aerodynamic Heating, WADC TR 58-378, Bell Aircraft Corp., June, 1959.

APPENDIX A

PROGRAM LISTING OF

TRAP-ML

```
      PROGRAM TRAPML (INPUT,OUTPUT,TAPE1=INPUT,TAPE6=OUTPUT,
     1  TAPE5=129,TAPE8=514)
C
C     TRAP-ML IS A SPECIAL VERSION OF TRAP DEVELOPED FOR THE AIR FORCE
C       MATERIALS LABORATORY, WPAFB, BY KAMAN AVIDYNE, BURLINGTON,MA.
C     VERSION 1.0, SEPT., 1978.
C     TEMPERATURE VS. TIME PLOT INFORMATION IS WRITTEN TO TAPE8.
C       PROGRAM APLOT IS REQIRED TO GENERATE THE PLOTS.
C
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(5,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUR,LAYN(75),MCOR,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PRINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QR(50,3),
     8  QRAD,QRER(2,3),QPR(14),SEGL,T(75),TAM,TCUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TFS,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTR,Y(75),YSEG(4)
      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HOF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHOM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVEB(15)
C
      CALL TIN
C
    5 CALL SETUP
      IF (ISTOP.EQ.1) GO TO 100
      IF (DELTIM.EQ.0.0) CALL TSTEP
      CALL XHEAT (0)
      DO 10 IE=1,NEL
      TEMP(IE) = TAM
      IMELT(IE) = 0
   10 Q(IE) = 0.0
      TIME = 0.
      NPRINT = 0
      QFLU = 0.
C
      CALL XHEAT (2)
      CALL DTEMP(0)
      IF (IPLOT.GT.0) CALL RPLOT(0)
C
   70 IF (IPLOT.GT.0) CALL RPLOT(1)
      IF (NPRINT.GT.0) GO TO 75
      IF (PRINT.EQ.0.0) GO TO 77
      CALL PPRINT
      NPRINT=PRINT-0.5
      GO TO 77
   75 NPRINT=NPRINT-1
   77 TIME=TIME+DELTIM
      IF (TIME.GT.TSTOP) GO TO 90
      CALL XHEAT (2)
      CALL DTEMP(1)
      QFLU = QFLU + QRAD*DELTIM
      GO TO 70
C
   90 IF (IPLOT.GT.0) CALL RPLOT(2)
      GO TO 5
C
  100 ENDFILE 8
      REWIND 8
  120 STOP
      END
```

TRAPML

```
      BLOCK DATA

      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HOF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHOM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVEB(15)

C     ABSORPTIVITY.

      DATA NAT/4*2/,ALFAT/560*0.5/,TALF(1,1)/300.0/,
     1TALF(2,1)/1680.0/,TALF(1,2)/300.0/,TALF(2,2)/1680.0/,
     2TALF(1,3)/300.0/,TALF(2,3)/1662.0/,TALF(1,4)/300.0/,
     3TALF(2,4)/3495.0/

C     SPECIFIC HEAT, BTU/LB-DEG R.

      DATA NCPT/9,9,8,9/

C     MATERIAL 1, 2024-T3.
      DATA CPM/0.175,0.191,0.214,0.229,0.244,
     10.259,0.287,0.313,0.387,0.387,
C     MATERIAL 2, 7075-T6.
     20.174,0.190,0.213,0.230,0.250,
     30.281,0.307,0.332,0.389,0.389,
C     MATERIAL 3, AZ31B.
     40.237,0.246,0.264,0.281,0.298,
     50.312,0.324,0.336,0.336,0.336,
C     MATERIAL 4, TI-8MN.
     60.104,.1275,0.146,0.153,0.158,
     70.164,0.204,0.251,0.370,0.370/
C     MATERIAL 1, 2024-T3.
      DATA TCP/360.0,460.0,660.0,860.0,1060.0,
     11260.0,1360.0,1460.0,1680.0,1680.0,
C     MATERIAL 2, 7075-T6.
     2360.00,460.00,660.00,860.00,1060.0,
     31260.0,1360.0,1460.0,1680.0,1680.0,
C     MATERIAL 3, AZ31B.
     4360.00,460.00,660.00,860.00,1060.0,
     51260.0,1460.0,1662.0,1662.0,1662.0,
C     MATERIAL 4, TI-8MN.
     6360.00,660.00,960.00,1160.0,1260.0,
     71360.0,1860.0,2460.0,3495.0,3495.0/
C     THERMAL CONDUCTIVITY, BTU/IN-SEC-DEG R.

      DATA NCT/10,10,9,2/

C     MATERIAL 1, 2024-T3.
      DATA CONDL/0.001283,0.001875,0.002267,0.002421,0.002450,
     10.002411,0.002323,0.002189,0.002020,0.001485,
C     MATERIAL 2, 7075-T6.
     20.001312,0.001890,0.002089,0.002284,0.002377,
     30.002359,0.002240,0.002091,0.002000,0.001395,
C     MATERIAL 3,AZ31B.
     40.000901,0.000990,0.001161,0.001325,0.001470,
     50.001584,0.001659,0.001680,0.001700,0.001700,
C     MATERIAL 4, TI-8MN.
     60.000127,9*0.000405/

C     MATERIAL 1,2024-T3.
      DATA TCOND/360.0,660.0,860.0,960.0,1060.0,
     11160.0,1260.0,1360.0,1460.0,1680.0,
C     MATERIAL 2,7075-T6.
     2360.00,660.00,760.00,860.00,960.00,
     31060.0,1260.0,1460.0,1560.0,1680.0,
C     MATERIAL 3,AZ31B.
     4360.00,460.00,660.00,860.00,1060.0,
     51260.0,1460.0,1560.0,1662.0,1662.0,
C     MATERIAL 4,TI-8MN.
     6360.0,9*3495.0/

C     EMISSIVITY.

      DATA EMI/40*0.5/
```

BLOCKD

```
C       HEAT OF FUSION.
        DATA HOF/170.0,170.0,158.0,188.0/
C       DENSITY.
        DATA RHOM/0.100,0.101,0.064,0.171/
C       MELT TEMPERATURES FOR MATERIAL GIVEN,DEGREES R.
        DATA TMELT/1680.0,1680.0,1662.0,3495.0/
        DATA KLD/4*1/, NMATT/4/
        DATA NWL/14/
        DATA WAVEB/0.2, 0.375, 0.625, 0.875, 1.125, 1.375, 1.625, 1.875,
       1  2.25, 2.75, 3.25, 3.75, 4.25, 4.75, 5.25/
        DATA PI/3.1415926535898/
        END
                                                                BLOCKD
```

```
      SUBROUTINE CONVEC (IFIRST,PO,TAM,VEL,TEMP,EL,XCON,HCONO,IE,
     1  TR,QCON)
C
C     THIS ROUTINE CALCULATES THE CONVECTION LOSSES TO TO AIR-STREAM
C     COOLING.
C
      DIMENSION TEMP(75), EL(75),XCON(75)
      IF (IFIRST.GT.0) GO TO 40
      TAM = TAM + 459.69
      VC = AMAX1(VEL,30.)
      TS = TAM
      AT = SQRT(2402.4*TS)
      TES = TS*(1.0-0.2*(VC/AT)**2)
      PAM = PO*(1.0 - 0.2*(VC/AT)**2)**3.5
      TR = TES + .88*(TS - TES)
      XEFF = 1.15
      WRITE (6,10) TR
   10 FORMAT (32H0RECOVERY TEMPERATURE, DEG. R = E15.6)
      RETURN
C
C     CALCULATE CONVECTIVE HEAT FLOW.
C
   40 HCON = HCONO
      IF (HCONO.GT.0.0) GO TO 60
      TPRIM = .5*(TEMP(IE) + TES) + .22*(TR-TES)
      RUD = 3.7E6*PAM*(TPRIM+198.6)/TPRIM**2.5
      AK=(1.0-8.83E-6*TPRIM+3.58E-8*TPRIM**2)*2.0E-8*TPRIM**1.5/
     1(TPRIM+201.6)
      RE=RUD*VC*XEFF/12.0
      HCON=0.026*AK*RE**0.8/XEFF
   60 QCON = HCON*(TR-TEMP(IE))*EL(IE)
      RETURN
      END
```

CONVEC

```
      SUBROUTINE DTEMP(KC)
C
C     DTEMP CALCULATES HEAT FLOW BY CONDUCTION AND INTERNAL RADIATION
C     AND UPDATES TEMPERATURES FOR EACH ELEMENT.
C
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(6,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSJR,LAYN(75),MCOR,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PRINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QR(50,3),
     8  QRAD,QREF(2,3),QRR(14),SEGL,T(75),TAM,TCUT,TEE(3),TEMP(75)
      COMMON TFLUX(15),TES,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTP,Y(75),YSEG(4)
      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HOF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHOM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVEB(15)
C
C     UPDATES CRITICAL TEMPERATURE RATIO IF KC.NE.0
C     SET UP MATERIAL CONDUCTIVITIES AND SPECIFIC HEATS
C
      IU=NEL
      DO 30  IE=1,IU
      IF (IMELT(    IE).EQ.1) GO TO 30
      NM=IMAT(    IE)
      TEL=TEMP(    IE)
      IF (TEL.GE.TMELT(NM)) GO TO 27
    7 CALL  INT17 (7,TEL,NCT(NM),TCOND(1,NM),CONDL(1,NM),CKL(IE))
      IF (KLD(NM).EQ.2) GO TO 10
      CKD(IE)=CKL(IE)
      GO TO 20
   10 CALL  INT17 (8,TEL,NCT(NM),TCOND(1,NM),CONDD(1,NM),CKD(IE))
   20 IF (TEL.LT.TMELT(NM)-10.0) GO TO 25
   22 CP(IE)=0.1*HOF(NM)
      GO TO 30
   25 CALL  INT17 (11,TEL,NCPT(NM),TCP(1,NM),CPM(1,NM),CP(IE))
      GO TO 30
   27 I=NCT(NM)
      CKL(IE)=CONDL(I,NM)
      IF (KLD(NM).EQ.2) GO TO 28
      CKD(IE)=CKL(IE)
      GO TO 29
   28 CKD(IE)=CONDD(I,NM)
   29 I=NCPT(NM)
      GO TO 22
   30 CONTINUE
C
C     CALCULATE CONDUCTIVE HEAT FLOW
C
      ICCU=NCONDC
      DO 80  ICC=1,ICCU
      I=KCONDI(ICC)
      J=KCONDJ(ICC)
      IF (IMELT(    I)+IMELT(    J).GT.0) GO TO 80
      IF (KCPI(    ICC).EQ.2) GO TO 40
      CKI=CKL(I)
      GO TO 50
   40 CKI=CKD(I)
   50 IF (KCPJ(    ICC).EQ.2) GO TO 60
      CKJ=CKL(J)
      GO TO 70
   60 CKJ=CKD(J)
   70 OKIJ=CONDI(    ICC)/CKI+CONDJ(    ICC)/CKJ+CONDAG(    ICC)
      QC=(TEMP(    I)-TEMP(    J))/OKIJ
      QCOND(I) = QCOND(I) - QC
      QCOND(J) = QCOND(J) + QC
      Q(    I)=Q(    I)-QC
      Q(    J)=Q(    J)+QC
   80 CONTINUE
```

```
C     UPDATE TEMPERATURES AND MELT CONDITIONS
      IF (KC.EQ.0) GO TO 140
      DO 110   IE=1,IJ
      IF (IMELT(    IE).EQ.1) GO TO 110
      NM=IMAT(IE)
      TM=TMELT(NM)-10.0
      TEL=TEMP(IE)
      TEMP(    IE)=TEL+Q(    IE)*DELTIM/(WT(    IE)*CP(IE))
      IF (TEL.GT.TM) GO TO 104
      IF (TEMP(    IE).LE.TM) GO TO 105
      DQ=Q(    IE)-(TM-TEL)*WT(    IE)*CP(IE)/DELTIM
      TEMP(    IE)=TM+DQ*DELTIM/(WT(    IE)*0.1*HOF(NM))
  104 IF (TEMP(    IE).LT.TMELT(NM)) GO TO 105
      IS=ISEG(    IE)
      IF (IE.NE.IEL(IS)) GO TO 105
      IMELT(    IE)=1
      IEL(IS) = IEL(IS) + 1
      NELS(IS) = NELS(IS) - 1
      IL = LAYN(IE)
      NELL(IS,IL) = NELL(IS,IL) - 1
      TEMP(    IE)=0.0
      Q(    IE)=0.0
      IF (NELS(        IS).GT.0) GO TO 110
      IEL(IS) = 0
      JEL(IS) = 0
  105 CONTINUE
  110 CONTINUE
C
  140 RETURN
      END
```

DTEMP

```
      SUBROUTINE FLUX (IFIRST,NOPT,NFLUX,TFLUX,FLUXT,QDMAX,TCUT,T,QRAD)
C
C     THIS ROUTINE CALCULATES THE INSTANTANEOUS FLUX AS A FUNCTION OF
C       TIME.  THERE ARE THREE OPTIONS.
C
C     IFIRST - 0, FIRST PASS
C              1, ALL OTHER PASSES.
C     NOPT   - 1, 6000 WATT TUNGSTEN LAMP CHARACTERISTICS.
C              2, STEP FUNCTION.
C              3, ARBITRARY, POINT BY POINT (TCUT NOT USED).
C     NFLUX, TFLUX, FLUXT - DEFINE FLUX TABLE VS. TIME.
C     QDMAX - PEAK FLUX
C     TCUT  - TIME AT WHICH THERMAL EXPOSURE IS CUT OFF.
C     T - TIME
C     QRAD - INSTANTANEOUS VALUE OF FLUX.
C
      DIMENSION TFLUX(15), FLUXT(15), TRISE(8),QDRISE(8),TFALL(8),
     1   QDFALL(8)
      DATA NRISE/8/, NFALL/8/
      DATA TRISE/0.,0.14,0.22,0.32,0.47,0.72,3.87,100./,
     1   QDRISE/0.,4.8,5.5,5.89,6.12,6.22,6.4,6.4/
      DATA TFALL/0.,.16,.23,.35,.54,1.25,2.85,100./
      DATA QDFALL/0.0,2.4,1.5,.83,.47,.18,2*0.0/
C
      IF (IFIRST.GT.0) GO TO 1100
      IF (NOPT-2) 100,600,700
C
C     OPTION 1.
C
  100 DO 200 I=2,NRISE
      II = I
      IF (TRISE(I).GT.TCUT) GO TO 300
  200 CONTINUE
  300 CALL INT1Z(2,TCUT,NRISE,TRISE,QDRISE,QDM)
      QDRAT = QDMAX/QDM
      QDFALL(1) = QDM
      II = II -1
      DO 400 I=1,II
      TFLUX(I) = TRISE(I)
  400 FLUXT(I) = QDRISE(I)*QDRAT
      III = II
      DO 500 I=1,NFALL
      III = III + 1
      TFLUX(III) = TFALL(I) + TCUT
  500 FLUXT(III) = QDFALL(I)*QDRAT
      NFLUX = II + NFALL
      GO TO 1000
C
C     OPTION 2.
C
  600 TFLUX(1) = 0.
      TFLUX(2) = TCUT
      TFLUX(3) = TCUT + 1.E-5
      TFLUX(4) = 100.
      FLUXT(1) = QDMAX
      FLUXT(2) = QDMAX
      FLUXT(3) = 0.
      FLUXT(4) = 0.
      NFLUX = 4
      GO TO 1000
C
C     OPTION 3.
C
  700 QDM = 0.
      DO 800 I=1,NFLUX
      IF (FLUXT(I) .GT.QDM) QDM = FLUXT(I)
  800 CONTINUE
      QDRAT = QDMAX/QDM
      DO 900 I=1,NFLUX
  900 FLUXT(I) = FLUXT(I)*QDRAT
C
 1000 JL = 2
      RETURN
```

```
C
C     TIME .GT. 0.
C
 1100 DO 1200 J=JL,NFLUX
      IF (TFLUX(J).GT.T) GO TO 1300
 1200 CONTINUE
      JL = NFLUX
      QRAD = FLUXT(JL)
      GO TO 1400
 1300 JL = J
      Q1 = FLUXT(J-1)
      T1 = TFLUX(J-1)
      QRAD = Q1 + (T-T1)*(FLUXT(J)-Q1)/(TFLUX(J)-T1)
 1400 RETURN
      END
```

FLUX

```
      SUBROUTINE INT1Z (ICODE,X,NX,XT,YT,R)
C
C     SUBROUTINE INT1 IS A LINEAR INTERPOLATION ROUTINE.
C     GIVEN A VALUE X, INT1 RETURNS THE CORRESPONDING VALUE Y.
C     ICODE - CODE FROM CALLING PROGRAM FOR TRACEBACK IN CASE OF ERROR.
C     NX = DIMENSION OF X-TABLE AND Y-TABLE IN CALLING PROGRAM.
C     XT = TABLE OF X-VALUES IN CALLING PROGRAM.
C     YT = TABLE OF Y-VALUES IN CALLING PROGRAM.
C     R = RETURN VALUE Y.
C
      DIMENSION XT(1),YT(1)
      IF (X-XT(1))1,8,2
    1 WRITE(6,11) X,(XT(I),I=1,NX)
      GO TO 10
    2 IF (X-XT(NX)) 4,9,3
    3 WRITE(6,11) X,(XT(I),I=1,NX)
      GO TO 10
    4 DO 5  I=2,NX
      IF (X-XT(I)) 7,6,5
    5 CONTINUE
    6 R=YT(I)
      RETURN
    7 R=YT(I-1)+(X-XT(I-1))*(YT(I)-YT(I-1))/(XT(I)-XT(I-1))
      RETURN
    8 R=YT(1)
      RETURN
    9 R=YT(NX)
      RETURN
   10 WRITE (6,12) (YT(I),I=1,NX)
      WRITE (6,14) ICODE
      STOP
C
C     FORMAT STATEMENTS -
C
   11 FORMAT (9H X-VALUE E12.5,1X,14HOUTSIDE TABLE./
     1 1X,9HX-TABLE =./(6(2X,E12.5)))
   12 FORMAT (9H YTABLE = /(1X,6E14.5))
   14 FORMAT (33H0TRACEBACK ERROR CODE IN INT1Z = I4)
      END
```

INT1Z

```
      SUBROUTINE RPLOT (KP)
C     THIS ROUTINE SETS UP THE PLOT FILES FOR TEMP VS TIME.
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(5,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUR,LAYN(75),MCOP,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PRINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QP(50,3),
     8  QRAD,QREF(2,3),QRP(14),SEGL,T(75),TAM,TCUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TFS,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTP,Y(75),YSEG(4)
      DIMENSION TEM(6)
C     NPOINT - MAXIMUM NUMBER OF POINTS TO BE PLOTTED.
      DATA NPOINT/200/
C
      IF (KP-1) 100,400,800
C
  100 NPLOT = 0
      N = (TSTOP + DELTIM)/DELTIM
      NUPLOT = 2*N/NPOINT
      IF (NUPLOT.EQ.0) NUPLOT = 1
C     SET UP PLOT FOR EACH SURFACE AND LAYER BOUNDARY.
      DO 300 IS=1,NSEG
      ILU = NLAY(IS)
      IELAY(1,IS) = IEL(IS)
      DO 200 IL=1,ILU
  200 IELAY(IL+1,IS) = IELAY(IL,IS) + NELL(IS,IL)
  300 IELAY(ILU+1,IS) = IELAY(ILU+1,IS) - 1
      IS = 1
      IF (NSEG.GT.1) IS = 2
      ILU = NLAY(IS)
      ILU1 = ILU + 1
C     NSP IS THE NUMBER OF SEGMENTS PLOTTED.
      NSP = 1
      WRITE (8) (ID(I),I=1,20),QDMAX,TCUT,ILU1,NOPT,NSP
      NPTS = 0
      RETURN
C
  400 IF (NPLOT.GT.0) GO TO 700
      NPLOT = NUPLOT
      NPTS = NPTS + 1
C     OUTER SURFACE.
      IE = IELAY(1,IS)
      TEM(1) = TEMP(IE)
      IF (TEM(1).EQ.0.0) GO TO 440
      IF (NELL(IS,1).LE.1) GO TO 440
      TEM(1) = TEMP(IE) + 0.5*(TEMP(IE) - TEMP(IE+1))
C     INNER SURFACE.
  440 IE = IELAY(ILU1,IS)
      TEM(ILU1) = TEMP(IE)
      IF (TEM(ILU1).EQ.0.0) GO TO 480
      IF (NELL(IS,ILU).LE.1) GO TO 480
      TEM(ILU1) = TEMP(IE) + .5*(TEMP(IE) - TEMP(IE-1))
C     LAYER BOUNDARIES.
  480 IF (ILU.EQ.1) GO TO 650
      DO 600 IL=2,ILU
      IE = IELAY(IL,IS)
      TA = TEMP(IE-1)
      IF (TA.EQ.0.0) GO TO 520
      T1 = TA
      IF (NELL(IS,IL-1).LE.1) GO TO 520
      TA = TA + .5*(TA - TEMP(IE-2))
  520 TB = TEMP(IE)
      IF (TB.EQ.0.0) GO TO 580
      T2 = TB
      IF (NELL(IS,IL).LE.1) GO TO 560
      TB = TB + .5*(TB - TEMP(IE+1))
  560 IF (TA*TB.EQ.0.0) GO TO 580
      TE       = 0.5*(TA + TB)
      IF (T2.GT.T1) GO TO 565
```

```
      TE = AMAX1(TE,T2)
      TE = AMIN1(TE,T1)
      GO TO 570
  565 TE = AMAX1(TE,T1)
      TE = AMIN1(TE,T2)
  570 TEM(IL) = TE
      GO TO 600
  580 TEM(IL) = AMAX1(TA,TB)
  600 CONTINUE
  650 CONTINUE
      WRITE (8) TIME, (TEM(I),I=1,ILU1)
  700 NPLOT = NPLOT - 1
      RETURN
C
  800 ENDFILE 8
      WRITE (6,1000)  ILU1,NPTS
      IPLOT = NPTS
 1000 FORMAT (30H0NUMBER OF CURVES GENERATED = I4/
     1  30H NUMBER OF POINTS PER CURVE = I4)
      RETURN
      END
```

RPLOT

```
      SUBROUTINE RPRINT
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCOND,ID(20),
     3  IEL(3),IFLAY(5,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUR,LAYN(75),MCOP,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLT,PO,
     7  RPINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QR(50,3),
     8  QRAD,QRER(2,3),QRP(14),SEGL,T(75),TAM,TOUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TFS,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTR,Y(75),YSEG(4)
C
      WRITE (6,1000) TIME,QRAD,QFLU
      WRITE (6,1100)
      DO 90 IE=1,NEL
      IS = ISEG(IE)
      IE1 = IEL(IS)
      IE2 = JEL(IS)
      IF (IE.EQ.IE1) GO TO 50
      IF (IE.EQ.IE2) GO TO 60
      WRITE (6,1200) IS,IE,TEMP(IE),QCOND(IE),Q(IE)
      GO TO 90
   50 IF (IE.EQ.IE2) QRER(1,IS) = QRER(1,IS) + QRER(2,IS)
      WRITE (6,1300) IS,IE,TEMP(IE),QAB(IS),QRER(1,IS),
     1  QCONV(IS),QCOND(IE),Q(IE)
      GO TO 90
   60 WRITE (6,1400) IS,IE,TEMP(IE),QRER(2,IS),QCOND(IE),Q(IE)
   90 CONTINUE
      RETURN
C
 1000 FORMAT (13H0TIME, SEC = E14.6/
     1  34H    INCIDENT FLUX, BTU/IN**2/SEC = E14.6/
     2  34H    INCIDENT FLUENCE, BTU/IN**2  = E14.6)
 1100 FORMAT (31H0  SEGMENT  ELEMENT TEMPERATURE,9X,
     1  37HH E A T     F L O W ,     B T U / S E C/
     2  29H    NUMBER   NUMBER    DEGREES R,4X,
     3  49HABSORPTION   RERADIATION    CONVECTION    CONDUCTION,6X,3HNET)
 1200 FORMAT (1H ,I6,6X,I2,4X,E11.4,41X,E11.4,2X,E11.4)
 1300 FORMAT (1H ,I6,6X,I2,4X,E11.4,5(2X,E11.4))
 1400 FORMAT (1H ,I6,6X,I2,4X,E11.4,15X,E11.4,13X,2(2X,E11.4))
      END
```

RPRINT

```
      SUBROUTINE SETUP
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(5,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUP,LAYN(75),MCOR,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPPINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PPINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QR(50,3),
     8  QRAD,QRER(2,3),QRR(14),SEGL,T(75),TAM,TCUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TES,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTP,Y(75),YSEG(4)
      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HOF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHOM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVEB(15)
      DIMENSION PRCOR(8),PRKCH(22)
      DATA PRCOP/10HALUMINUM, ,10HALUMINUM, ,10HMAGNESIUM,,10HTITANIUM,
     1,10H2024-T3    ,10H7075-T6    ,10H A7318-H24,10HTI-8MN     /
      DATA PRKCH/10HABSORPTIVI,10HCONDUCTIVI,10HTHERMAL EX,10HSPECIFIC H
     1,10HMELTING TE,10HHEAT OF FU,10HMODULUS OF,10HTENSILE YI,
     210HTENSILE UL,10HULTIMATE S,10HDENSITY   ,2HTY,2HTY,7HPANSION,
     33HEAT,10HMPERATURE ,4HSION,10H ELASTICTY,10HELD STRESS,
     410HTIMATE STR,5HTRAIN,1H /
      DATA IEN1/4HEND /, IEN2/4H    /
C
    1 FORMAT (6I12)
    2 FORMAT (6F12.1)
    3 FORMAT (20A4)
      ISTOP=0
      READ (5,3) (ID(I),I=1,20)
      IF(ID(1).NE.IEN1.OR.ID(2).NE.IEN2) GO TO 4
      ISTOP=1
      GO TO 899
    4 READ(5,1) INOUT,IPLOT
      IF (INOUT.GT.0) WRITE (6,951) (ID(I),I=1,20),IPLOT
  951 FORMAT (1H1,20A4//30H PLOT CODE (0 FOR NO PLOTS) = I2)
      DO 5 I=1,NWL
    5 WAVEL(I)=.5*(WAVEB(I)+WAVEB(I+1))
      XMIN=10.0E10
      XMAX=-10.0E10
      IK=1
      NEL=0
      NMAT=NMATT
      KSUP=1
      NS = 1
      READ(5,1) NSEG
      ISU=NSEG+1
      DO 13  IS=1,ISU
      READ(5,2) XSEG(IS),YSEG(IS)
      XMIN=AMIN1(XMIN,XSEG(IS))
   13 XMAX=AMAX1(XMAX,XSEG(IS))
      ISU = ISU - 1
      DO 26 IS=1,ISU
      READ(5,1) NLAY(IS)
      ILU=NLAY(IS)
      DO 14  IL=1,ILU
      READ (5,2) TLAY(IS,IL)
      READ(5,1) KMAT(IS,IL),NELL(IS,IL)
      NMAT=MAX0(NMAT,KMAT(IS,IL))
   14 CONTINUE
C
C     CALCULATE SEGMENT LENGTHS
C
      DX=XSEG(IS+1)-XSEG(IS)
      DY=YSEG(IS+1)-YSEG(IS)
      SEGL=SQRT(DX**2+DY**2)
      DX=DX/SEGL
      DY=DY/SEGL
      DXL=DX
      DYL=DY
C
C     SET UP ELEMENT NUMBERING SYSTEM,CALCULATE ELEMENT THICKNESS,
```

```
C     AREA, WEIGHT,LENGTH,POSITION
      IEL(IS)=NEL+1
      DO 25  IL=1,ILU
      THICK=TLAY(IS,IL)/FLOAT(NELL(IS,IL))
      AREA=THICK*SEGL
      IF (IL.GT.1) GO TO 22
      IET=IEL(IS)
      X(IET)=0.5*(XSEG(IS)+XSEG(IS+1)+THICK*DYL)
      Y(IET)=0.5*(YSEG(IS)+YSEG(IS+1)-THICK*DXL)
   22 IELL=NEL+1
      IELU=NEL+NELL(IS,IL)
      IF(IELU.LE.75) GO TO 23
      WRITE (6,941) NS
      STOP
   23 DO 24  IE=IELL,IELU
      LAYN(IE) = IL
      IMAT(IE)=KMAT(IS,IL)
      ISEG(IE)=IS
      T(IE)=THICK
      EL(IE)=SEGL
      A(IE)=AREA
      IF(IE.EQ.IET) GO TO 24
      X(IE)=X(IE-1)+0.5*(T(IE-1)+T(IE))*DYL
      Y(IE)=Y(IE-1)-0.5*(T(IE-1)+T(IE))*DXL
   24 CONTINUE
   25 NEL=IELU
      NELS(IS)=IELU+1-IEL(IS)
      JEL(IS) = NEL
   26 CONTINUE
      IF (INOUT.EQ.0) GO TO 29
      WRITE(6,910) NSEG
      ISU = NSEG + 1
      WRITE(6,904)  (XSEG(IS),IS=1,ISU)
      WRITE(6,905)  (YSEG(IS),IS=1,ISU)
      ISU = ISU - 1
      DO 912 IS=1,ISU
      ILU=NLAY(IS)
      WRITE (6,911) IS,ILU
      WRITE (6,913) (IL,TLAY(IS,IL),KMAT(IS,IL),NELL(IS,IL),IL=1,ILU)
  912 CONTINUE
C     CALCULATE HEAT CONDUCTION CONSTANTS FOR ELEMENTS WITHIN BRANCH
   29 DO 40  IS=1,ISU
      ISC=1
      IELLI=IEL(IS)
      IELUI=IELLI-1+NELS(IS)
      IF (IS.LT.ISU) GO TO 31
      IF(XSEG(1).NE.XSEG(IS+1).OR.YSEG(1).NE.YSEG(IS+1)) GO TO 33
      IELLJ=IEL(1)
      IELUJ=IELLJ-1+NELS(1)
      GO TO 32
   31 IELLJ=IEL(IS+1)
      IELUJ=IELLJ-1+NELS(IS+1)
   32 DBI=0.0
      DTJ=0.0
      DBJ=T(IELLJ)
      IEJ=IELLJ
      GO TO 34
   33 ISC=0
   34 DO 39  IEI=IELLI,IELUI
      IF (ISC.EQ.0) GO TO 38
      DTI=DBI
      DBI=DTI+T(IEI)
C     ELEMENTS OF ADJACENT SEGMENTS
   35 BIJ=AMIN1(DBI,DBJ)-AMAX1(DTI,DTJ)
      KCONDI(IK)=IEI
      KCONDJ(IK)=IEJ
      B(IK)=BIJ
      CONDI(IK)=EL(IEI)/(2.0*BIJ)
```

```
      CONDJ(IK)=EL(IEJ)/(2.0*BIJ)
      CONDAG(IK)=0.0
      KCPI(IK)=1
      KCPJ(IK)=1
      IK=IK+1
      IF (DBJ.GT.DBI) GO TO 38
      IF (IEJ.NE.IELUJ) GO TO 36
      ISC=0
      GO TO 38
   36 IEJ=IEJ+1
      DTJ=DBJ
      DBJ=DTJ+T(IEJ)
      IF (DTJ.LT.DBI) GO TO 35
C
C     ELEMENTS OF SAME SEGMENT
C
   38 IF (IEI.EQ.IELUI) GO TO 40
      KCONDI(IK)=IEI
      KCONDJ(IK)=IEI+1
      BIJ=EL(IEI)
      B(IK)=BIJ
      CONDI(IK)=T(IEI)/(2.0*BIJ)
      CONDJ(IK)=T(IEI+1)/(2.0*BIJ)
      CONDAG(IK)=0.0
      KCPI(IK)=2
      KCPJ(IK)=2
      IK=IK+1
   39 CONTINUE
   40 CONTINUE
      NCONDC = IK-1
C
C     SET UP MATERIAL PROPERTIES TABLES FOR ADDED MATERIALS
C
      NML=NMATT+1
      IF (NML.GT.NMAT) GO TO 260
      DO 250  NM=NML,NMAT
      READ (5,1) MCOR
      IF (MCOR.EQ.0) GO TO 115
      IF (INOUT.EQ.0) GO TO 113
      IF(MCOR.GT.NMATT) GO TO 112
      WRITE (6,935) NM,PRCOR(MCOR),PRCOR(MCOR+4)
      GO TO 113
  112 WRITE (6,9351) NM,MCOR
  113 READ (5,1) KCH
      IF (KCH.EQ.1) GO TO 115
      NAT(NM)=NAT(MCOR)
      NTJ=NAT(NM)
      DO 114 NT=1,NTJ
      TALF(NT,NM)=TALF(NT,MCOR)
      EMI(NT,NM)=EMI(NT,MCOR)
      DO 114 NW=1,NWL
  114 ALFAT(NT,NW,NM)=ALFAT(NT,NW,MCOR)
      GO TO 120
  115 READ (5,1) NAT(NM)
      NTJ=NAT(NM)
      IF (INOUT.EQ.1) WRITE (6,936) PRKCH(1),PRKCH(12)
      IF (INOUT.EQ.1) WRITE (6,918) NAT(NM)
      DO 118  NT=1,NTJ
      READ (5,2) TALF(NT,NM),EMI(NT,NM)
      READ (5,1) NWLA
      DO 116  NW=1,NWLA
  116 READ (5,2) WL(NW,NT),ALF(NW,NT)
      DO 117  NW=1,NWL
      CALL INT17 (12,WAVEL(NW),NWLA,WL(1,NT),ALF(1,NT),ALFAT(NT,NW,NM))
  117 CONTINUE
      IF (INOUT.EQ.0) GO TO 118
      WRITE (6,919) TALF(NT,NM),EMI(NT,NM),NWLA,(WL(NW,NT),ALF(NW,NT),NW
     1=1,NWLA)
  118 CONTINUE
  120 IF (MCOR.EQ.0) GO TO 125
      IF (KCH.LT.2) READ (5,1) KCH
      IF (KCH.EQ.2) GO TO 125
      NCT(NM)=NCT(MCOR)
```

```
      KLD(NM)=KLD(MCOR)
      NTJ=NCT(NM)
      DO 122  NT=1,NTJ
      TCOND(NT,NM)=TCOND(NT,MCOR)
      CONDL(NT,NM)=CONDL(NT,MCOR)
      IF (KLD(NM).EQ.1) GO TO 122
      CONDD(NT,NM)=CONDD(NT,MCOR)
  122 CONTINUE
      GO TO 130
  125 READ (5,1) KLD(NM)
      READ (5,1) NCT(NM)
      NTJ=NCT(NM)
      DO 128  NT=1,NTJ
      READ (5,2) TCOND(NT,NM),CONDL(NT,NM),CONDD(NT,NM)
      IF (KLD(NM).EQ.1) CONDD(NT,NM) = CONDL(NT,NM)
  128 CONTINUE
      IF (INOUT.EQ.0) GO TO 130
      WRITE (6,936) PRKCH(2),PRKCH(13)
      WRITE (6,920) KLD(NM),NCT(NM),(TCOND(NT,NM),CONDL(NT,NM),CONDD(NT,
     1NM),NT=1,NTU)
  130 IF(MCOR.EQ.0) GO TO 145
      IF (KCH.EQ.0) GO TO 141
      IF (KCH.LT.4) READ (5,1) KCH
      IF (KCH.EQ.4) GO TO 145
  141 NCPT(NM) = NCPT(MCOR)
      NTU = NCPT(NM)
      DO 142 NT=1,NTU
      TCP(NT,NM) = TCP(NT,MCOR)
  142 CPM(NT,NM) = CPM(NT,MCOR)
      GO TO 150
  145 READ (5,1) NCPT(NM)
      NTJ=NCPT(NM)
      DO 148  NT=1,NTJ
  148 READ (5,2) TCP(NT,NM),CPM(NT,NM)
      IF (INOUT.EQ.0) GO TO 150
      WRITE (6,936) PRKCH(4),PRKCH(15)
      WRITE (6,922) NCPT(NM),(TCP(NT,NM),CPM(NT,NM),NT=1,NTU)
  150 IF (MCOR.EQ.0) GO TO 155
      IF (KCH.EQ.0) GO TO 151
      IF (KCH.LT.5) READ (5,1) KCH
      IF (KCH.EQ.5) GO TO 155
  151 TMELT(NM)=TMELT(MCOR)
      GO TO 160
  155 READ (5,2) TMELT(NM)
      IF (INOUT.EQ.0) GO TO 160
      WRITE (6,936) PRKCH(5),PRKCH(16)
      WRITE (6,923) TMELT(NM)
  160 IF (MCOR.EQ.0) GO TO 165
      IF (KCH.EQ.0) GO TO 161
      IF (KCH.LT.6) READ (5,1) KCH
      IF (KCH.EQ.6) GO TO 165
  161 HOF(NM)=HOF(MCOR)
      GO TO 170
  165 READ (5,2) HOF(NM)
      IF (INOUT.EQ.0) GO TO 170
      WRITE (6,936) PRKCH(6),PRKCH(17)
      WRITE (6,924) HOF(NM)
  170 IF(MCOR.EQ.0) GO TO 215
      IF (KCH.EQ.0) GO TO 211
      IF (KCH.LT.11) READ (5,1) KCH
      IF (KCH.EQ.11) GO TO 215
  211 RHOM(NM) = RHOM(MCOR)
      GO TO 220
  215 READ (5,2) RHOM(NM)
      IF (INOUT.EQ.0) GO TO 217
      WRITE (6,936) PRKCH(11),PRKCH(22)
      WRITE (6,929) RHOM(NM)
  217 READ (5,1) KCH
      IF (KCH.EQ.0) GO TO 220
      WRITE (6,218) NM
  218 FORMAT (60H0MATERIAL PROPERTY CHANGES IMPROPERLY SPECIFIED FOR MAT
     1ERIAL I2)
```

```
C       DETERMINE EMISSIVITIES OF ADDED MATERIALS IF REQUIRED

  220 IF (EMI(1,NM).GT.0.0) GO TO 250
      NTU=NAT(NM)
      DO 240 NT=1,NTU
      NP=0
      EMISS=0.0
      WL1=259000.0/TALF(NT,NM)
      DO 230  N=3,130
      FN=N
      ZETA=0.1*FN
      WL2=WL1/FN
      IF (WL2.LT.WL(1,NT).OR.WL2.GT.WL(NWLA,NT)) GO TO 228
      CALL INT1Z(4,WL2,NWLA,WL(1,NT),ALF(1,NT),AL)
      EMISS=EMISS+AL*ZETA**3/(EXP(ZETA)-1.0)
      GO TO 230
  228 IF (NP.GT.0) GO TO 230
      NP=1
      WRITE (6,229) NM,NT
  229 FORMAT (14H0FOR MATERIAL ,I2,16H AT TEMPERATURE ,I2,
     178H. INTEGRATION FOR EMISSIVITY REQUIRES ABSORPTIVITIES OUTSIDE OF
     2 RANGE PROVIDED,/44H ABSORPTIVITIES TAKEN AS 0 WHERE UNAVAILABLE)
  230 CONTINUE
      EMI(NT,NM)=1.5*EMISS/PI**4
  240 CONTINUE
  250 CONTINUE
  260 IEU=NEL
      DO 270 IE=1,IEU
      NM=IMAT(IE)
  270 WT(IE)=A(IE)*RHOM(NM)
      DO 390  IE=1,IEU
  390 IMELT(IE) = 0

C       SET UP DISTANCES FROM LEADING EDGE FOR CONVECTION

      ISU=NSEG
      DO 480  IS=1,ISU
      IE=IEL(IS)
      XCON(IE) = X(IE)
      IE1 = IE + 1
      IEJ = IE + NELS(IS) - 1
      IF (IEU.LT.IE1) GO TO 480
      DO 460 I=IE1,IEJ
  460 XCON(I) = XCON(IE)
  480 CONTINUE
      READ (5,2) VEL,PO,TAM,HCONO
      IF(INOUT.EQ.0) GO TO 500
      WRITE (6,952) VEL,PO,TAM
      IF(HCONO.GT.0.0) WRITE(6,953) HCONO
  500 READ(5,1) NOPT
      IF(INOUT.GT.0) WRITE(6,954) NOPT
      READ(5,2) ODMAX
      IF(INOUT.GT.0) WRITE(6,955) ODMAX
      IF(NOPT.EQ.3) GO TO 550
      READ(5,2) TCUT
      IF(INOUT.GT.0) WRITE(6,956) TCUT
      GO TO 600
  550 READ(5,1) NFLUX
      IF(INOUT.GT.0) WRITE(6,957)
      DO 580 I=1,NFLUX
      READ(5,2) TFLUX(I),FLUXT(I)
      IF(INOUT.GT.0) WRITE(6,958) I,TFLUX(I),FLUXT(I)
  580 CONTINUE
  600 NTSPEC=1
      READ(5,1) NWLI,NTSPEC
      IF(NWLI.EQ.0) GO TO 700
      IF(INOUT.GT.0) WRITE(6,959) NWLI,NTSPEC
      IF(NTSPEC.EQ.1) GO TO 650
      READ(5,2) (TSPEC(I),I=1,NTSPEC)
      IF(INOUT.GT.0) WRITE(6,960) (TSPEC(I),I=1,NTSPEC)
  650 IF(INOUT.GT.0) WRITE(6,961)
      DO 680 I=1,NTSPEC
      DO 680 J=1,NWLI
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      READ(5,2) WAVE(J,I),QP(J,I)
      IF(INOUT.GT.0) WRITE(6,362) I,J,WAVE(J,I),QP(J,I)
  640 CONTINUE
  720 READ(5,2) DELTIM,TSTOP,PRINT
      IF(INOUT.GT.0) WRITE(6,940) DELTIM,TSTOP,PRINT
      DTIME=0.0
      WRITE (6,903)
      IEU=NEL
      DO 840 IE=1,IEU
      IS = ISEG(IE)
      IF (IE.NE.IEL(IS)) GO TO 800
      IL = 1
      GO TO 820
  800 IF (IMAT(IE).EQ.IMAT(IE-1).AND.T(IE).EQ.T(IE-1)) GO TO 820
      IL = IL + 1
  820 WRITE (6,902) IE,IS,IL,IMAT(IE),T(IE)
  840 CONTINUE
  999 RETURN
C
  902 FORMAT (1X,I4,          11X,I4,11X,I4,12X,I4,11X,F7.4)
  903 FORMAT (26H1 SUMMARY OF THERMAL MODEL/8H0ELEMENT,7X,7HSEGMENT,1X,
     13X,5HLAYER,10X,3HMATERIAL,7X,9HTHICKNESS/
     27H NUMBER,              9X,6HNUMBER,9X,6HNUMBER,11X,4HCODE,11X,
     34H(IN)//)
  904 FORMAT (16H X COORDINATE,IN/(1X,5E15.7))
  905 FORMAT (16H Y COORDINATE,IN/(1X,5E15.7))
  910 FORMAT (29H0NUMBER OF SEGMENTS              ,I5)
  911 FORMAT (15H0SEGMENT NUMBER,I3/28H NUMBER OF LAYERS IN SEGMENT/
     1(20I5))
  913 FORMAT (13H0LAYER NUMBER ,5X,29H THICKNESS OF LAYER (TLAY),IN,5X,
     132H CODE DEFINING MATERIAL OF LAYER,5X,28H NUMBER OF ELEMENTS IN L
     2AYER/I6X,I2,12X,E15.7,20X,I15,20X,I15))
  918 FORMAT (40H NUMBER OF TEMPERATURES FOR ABSORPTIVITY,I5)
  919 FORMAT (25H TEMPERATURE (TALF),DEG.R,F15.7,5X,16HEMISSIVITY (EMI),
     1E15.7/23H NUMBER OF WAVE LENGTHS,I5/25H WAVE LENGTH (WL),MICRONS,
     210X,1-HABSORPTIVITY (ALF)/(5X,E15.7,17X,E15.7))
  920 FORMAT (5H CODE,I5,44H AND NUMBER OF TEMPERATURES FOR CONDUCTIVITY
     1,I5/26H TEMPERATURE (TCOND),DEG.R,5X,36H LENGTHWISE (CONDL),BTU/IN
     2-SEC-DEG.R,5X,35H DEPTHWISE (CONDD),BTU/IN-SEC-DEG.R,5X/
     3(5X,E15.7,21X,E15.7,26X,E15.7))
  922 FORMAT (41H NUMBER OF TEMPERATURES FOR SPECIFIC HEAT,I5/
     124H TEMPERATURE (TCP),DEG.R,10X,33H SPECIFIC HEAT (CPM),BTU/LB-DEG
     2.R/(5X,E15.7,23X,E15.7))
  923 FORMAT (34H MELTING TEMPERATURE (TMELT),DEG.R,2X,E15.7)
  924 FORMAT (28H HEAT OF FUSION (HOF),BTU/LB,2X,E15.7)
  929 FORMAT (25H DENSITY (RHOM),LBS-IN**3,2X,E15.7//)
  935 FORMAT (20H0NEW MATERIAL NUMBER, I3/
     1          50H MATERIAL TO WHICH NEW MATERIAL CORRESPONDS (MCOR),
     2          2A10)
 9351 FORMAT (20H0NEW MATERIAL NUMBER, I3/
     1          50H MATERIAL TO WHICH NEW MATERIAL CORRESPONDS (MCOR),I3)
  936 FORMAT (38H0MATERIAL PROPERTY TO BE CHANGED (KCH),2A10)
  940 FORMAT (17H0TIME INFORMATION/
     4          42H     INTEGRATION TIME INTERVAL (DELTIM),SEC,2X,E15.7/
     525H       STOP TIME (TSTOP),SEC,2X,E15.7/36H      NUMBER OF TIME INTERV
     1ALS (PRINT),2X,E15.7)
  941 FORMAT (9H1SECTION I2,36H CONTAINS MORE ELEMENTS THAN ALLOWED)
  952 FORMAT (34H0VELOCITY OF AIR STREAM, FT/SEC = E15.6/
     1   32H AMBIENT (ROOM) PRESSURE, PSI = E15.6/
     2   37H AMBIENT (ROOM) TEMPERATURE, DEG. F = E15.6)
  953 FORMAT(60H0CONVECTIVE HEAT TRANSFER COEFFICIENT  (BTU/IN**2/SEC/DR
     1) = E15.6)
  954 FORMAT(21H0THERMAL FLUX OPTION I3)
  955 FORMAT(35H0     MAXIMUM FLUX (BTU/IN**2/SEC) = E15.6)
  956 FORMAT(29H      FLUX CUTOFF AT T (SEC) = E15.6)
  957 FORMAT(1H0,14X,4HTIME,13X,4HFLUX)
  958 FORMAT(I7,2E15.6)
  959 FORMAT(40H0SPECTRAL DISTRIBUTION OF THERMAL SOURCE/
     129H       NUMBER OF WAVE LENGTHS = I2/22H     NUMBER OF TIMES = I2)
  960 FORMAT(20H0         TIMES (SEC) = 5E17.6)
  961 FORMAT(1H0,5X,1HI,3X,1HJ,5X,10HWAVELENGTH,8X,4HFLUX)
  962 FORMAT(I7,I4,4X,2E15.6)
      END
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SETUP

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      SUBROUTINE SPECT (IFIRST,NTSPEC,TSPEC,NWLI,WAVE,QR,NWL,
     1  WAVEL,WAVEB,T,QRR)
C
C     DETERMINE SPECTRAL DISTRIBUTION OF SOURCE AS A FUNCTION OF
C       14 WAVELENGTHS BETWEEN 0.2 MICRONS AND 5.5 MICRONS.
C     IFIRST - 0, FIRST PASS.
C              1, ALL OTHER PASSES.
C     NTSPEC - NUMBER OF TIMES THE SPECTRAL DISTRIBUTION IS SPECIFIED.
C     TSPEC - TIMES AT WHICH THE SPATIAL DISTRIBUTION IS SPECIFIED.
C     NWLI - NUMBER OF INPUT TABLE ENTRIES DEFINING DISTRIBUTION.  IF
C            0, USE BUILT-IN DISTRIBUTION FOR 6000 WATT TUNGSTEN LAMP.
C     WAVE - INPUT WAVELENGTHS.
C     QR - INPUT INTESITIES.
C     NWL - NUMBER OF STANDARD WAVELENGTHS - PROBABLY 14.
C     WAVEL - 14 STANDARD WAVELENGTHS.
C     WAVEB - 15 WAVELENGTHS DEFINING BAND WIDTHS OF WAVEL.
C     T - TIME.
C     QRR - RELATIVE INTENSITY FOR 14 WAVELENGTHS.
C
      DIMENSION QR(50,3),WAVE(50,3),WAVEX(15,3),QRX(15,3),
     1  QRRX(3,14),QRR(14),TSPEC(3),C(5)
      DIMENSION WAVEL(14),WAVEB(15)
      DATA NWLX/15/, WAVEX/0.2,0.375,0.625,0.875,1.125,1.375,1.625,
     1  1.875,2.25,2.75,3.25,3.75,4.25,4.75,5.25, 30*0.0/
      DATA QRX/0.0,0.085,0.68,0.995,0.89,0.59,0.44,0.31,0.205,0.06,
     1  0.055,0.037,0.02,0.015,0.0, 30*0.0/
      DATA C/1.0,4.0,2.0,4.0,1.0/
C
      IF (IFIRST.GT.0) GO TO 600
      IF (NWLI.GT.0) GO TO 200
C     USE 6 KW TUNGSTEN LAMP.
      NTSPEC = 1
      NWLI = NWLX
      DO 100 J=1,NTSPEC
      DO 100 I=1,NWLI
      WAVE(I,J) = WAVEX(I,J)
  100 QR(I,J) = QRX(I,J)
C     INTEGRATE, USING SIMPSON'S RULE, OVER EACH BANDWIDTH.
  200 DO 500 J=1,NTSPEC
      QTOT = 0.0
      DO 400 I=1,NWL
      X1 = WAVEB(I)
      X5 = WAVEB(I+1)
      DELX = (X5-X1)/4.
      FF = 0.0
      DO 300 K=1,5
      CALL INT17(1,X1,NWLI,WAVE(1,J),QR(1,J),F)
      X1 = X1 + DELX
  300 FF = FF + F*C(K)
      QRR(I) = FF*(X5-X1)/12.
  400 QTOT = QTOT + QRR(I)
      DO 500 I=1,NWL
  500 QRRX(J,I) = QRR(I)/QTOT
      DO 550 I=1,NWL
  550 QRR(I) = QRRX(1,I)
      RETURN
C
C     SPECTRAL DISTRIBUTION VARIES WITH TIME.
C
  600 IF (NTSPEC.EQ.1) RETURN
      IF (T.GT.TSPEC(NTSPEC)) GO TO 800
      DO 700 I=1,NWL
      CALL INT17(3,T,NTSPEC,TSPEC,QRRX(1,I),QRR(I))
  700 CONTINUE
      RETURN
C
  800 DO 900 I=1,NWL
  900 QRR(I) = QRRX(NTSPEC,I)
      RETURN
      END
```

SPECT

```
      SUBROUTINE TIN
C
C     READ IN INPUT DATA.
C
      DIMENSION AA(40)
C
      WRITE (6,1000)
      REWIND 5
      J = 1
  100 READ (1,1) (AA(I),I=1,40)
      IF (EOF(1)) 400,200
  200 WRITE (6,2000) J,(AA(I),I=1,40)
      WRITE (5,1) (AA(I),I=1,40)
      J = J + 1
      GO TO 100
C
  400 WRITE (6,3000)
      REWIND 5
      RETURN
C
    1 FORMAT (40A2)
 1000 FORMAT (1H1,//,10X,15HT R A P  -  M L/
     1   15H0***  INPUT DATA/)
 2000 FORMAT (1X,I4,2X,40A2)
 3000 FORMAT (23H0***  END OF INPUT DATA)
      END
```

TIN

```
      SUBROUTINE TSTEP
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(5,3),IEND,IMAT(75),IMELT(75),INOJT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUR,LAYN(75),MCOR,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PRINT,Q(75),QAB(3),QCOND(75),QCONV(3),QOMAX,QFLU,QP(50,3),
     8  QRAD,QREF(2,3),QRR(14),SEGL,T(75),TAM,TCUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TFS,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVFL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTR,Y(75),YSEG(4)
      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HOF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHCM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVEB(15)
C
      T1=0.0
      T2=0.0
      IU=NEL
      DO 5 IE=1,IU
      NM=IMAT(IE)
      T1=AMAX1(T1,TCOND(1,NM),TCP(1,NM))
    5 T2=AMAX1(T2,TMELT(NM))
      DO 10 IE=1,IU
   10 DTIM(    IE)=100.0
      DO 70 NT=1,10
      TEL=T1+(FLOAT(NT-1)/9.0)*(T2-T1)
      DO 20 NM=1,NMAT
      IF (TEL.LT.TCOND(1,NM).OR.TEL.LT.TCP(1,NM)) GO TO 20
      IF (TEL.GT.TMELT(NM)) GO TO 15
      CALL  INT1Z (13,TEL,NCT(NM),TCOND(1,NM),CONDL(1,NM),CKLM(NM))
      IF (KLD(NM).EQ.2) GO TO 12
      CKDM(NM)=CKLM(NM)
      GO TO 13
   12 CALL  INT1Z (5,TEL,NCT(NM),TCOND(1,NM),CONDD(1,NM),CKDM(NM))
   13 CALL  INT1Z (6,TEL,NCPT(NM),TCP(1,NM),CPM(1,NM),CPMAT(NM))
      GO TO 20
   15 I=NCT(NM)
      CKLM(NM)=CONDL(I,NM)
      IF (KLD(NM).EQ.2) GO TO 17
      CKDM(NM)=CKLM(NM)
      GO TO 18
   17 CKDM(NM)=CONDD(I,NM)
   18 I=NCPT(NM)
      CPMAT(NM)=CPM(I,NM)
   20 CONTINUE
      DO 25 IE=1,IU
   25 Q(    IE)=0.0
      ICCJ=NCONDC
      DO 50 ICC=1,ICCJ
      I=KCONDI(ICC)
      J=KCONDJ(ICC)
      NM=IMAT(I)
      IF (KCPI(    ICC).EQ.2) GO TO 30
      CKI=CKLM(NM)
      GO TO 32
   30 CKI=CKDM(NM)
   32 NM=IMAT(J)
      IF (KCPJ(    ICC).EQ.2) GO TO 40
      CKJ=CKLM(NM)
      GO TO 42
   40 CKJ=CKDM(NM)
   42 OKIJ=CONDI(    ICC)/CKI+CONDJ(    ICC)/CKJ+CONDAG(    ICC)
      QC=1.0/OKIJ
      Q(    I)=Q(    I)+QC
   50 Q(    J)=Q(    J)+QC
      DO 60 IE=1,IU
      IF (Q(    IE).EQ.0.0) GO TO 60
      NM=IMAT(    IE)
      DTIM(    IE)=AMIN1(DTIM(    IE),WT(    IE)*CPMAT(NM)*0.8/Q(    IE))
   60 CONTINUE
   70 CONTINUE
```

TSTEP

```
      WRITE (6,110)
  110 FORMAT (26H0TIME INTERVAL INFORMATION)
      IU=NEL
      WRITE (6,120)     (DTIM(    IE),IE=1,IU)
  120 FORMAT (                33H0TIME INTERVAL REQUIRED BY EACH ELEMENT/
     1/(1H 10E13.5))
      DTMIN = DTIM(1)
      I=1
      IF (IU.EQ.1) GO TO 135
      DO 130 IE=2,IU
      IF (DTIM(    IE).GE.DTMIN) GO TO 130
      DTMIN = DTIM(IE)
      I=IE
  130 CONTINUE
  135 WRITE (6,140) DTMIN,I
  140 FORMAT (25H0MINIMUM TIME INTERVAL IS E13.5,
     1   21H SECONDS FOR ELEMENT I3)
  150 CONTINUE
      DELTIM=DTMIN
      DTIME=DELTIM
      RETURN
      END
```

TSTEP

```
      SUBROUTINE XHEAT (KR)
C
C     CALCULATES EXTERNAL RADIATION AND CONVECTION HEAT FLOWS
C     FOR EACH ELEMENT.
C     KR = 0, SETUP ONLY.
C          1, CONVECTION AND REPADIATION ARE CONSIDERED.
C          2, CONVECTION, RERADIATION, AND EXTERNAL RADIATION ARE USED.
C
      COMMON A(75),ALF(10,10),B(122),CKD(75),CKDM(9),CKL(75),CKLM(9),
     1  CONDAG(122),CONDD(10,9),CONDI(122),CONDJ(122),CP(75),CPMAT(9),
     2  DELTIM,DTIM(75),DTIME,DTMIN,EL(75),FLUXT(15),HCONO,ID(20),
     3  IEL(3),IELAY(6,3),IEND,IMAT(75),IMELT(75),INOUT,IPLOT,ISEG(75),
     4  ISTOP,JEL(3),KCH,KCONDI(122),KCONDJ(122),KCPI(122),KCPJ(122),
     5  KMAT(3,5),KSUR,LAYN(75),MCOR,NCONDC,NEL,NELL(3,5),NELS(3),
     6  NFLUX,NLAY(3),NMAT,NOPT,NPRINT,NSEG,NTSPEC,NWLA,NWLI,PO,
     7  PRINT,Q(75),QAB(3),QCOND(75),QCONV(3),QDMAX,QFLU,QR(50,3),
     8  QRAD,QRER(2,3),QRR(14),SEGL,T(75),TAM,TCUT,TEF(3),TEMP(75)
      COMMON TFLUX(15),TFS,TIME,TLAY(3,5),TP(75),TR,TSPEC(3),TSTOP,
     1  VEL,WAVE(50,3),WAVEL(14),WL(10,10),WT(75),X(75),XCON(75),
     2  XSEG(4),XTR,Y(75),YSEG(4)
      COMMON /BLOCK/ ALFAT(10,14,9),CONDL(10,9),CPM(10,9),EMI(10,9),
     1  HDF(9),KLD(9),NAT(9),NCPT(9),NCT(9),NMATT,NWL,PI,RHOM(9),
     2  TALF(10,9),TCOND(10,9),TCP(10,9),TMELT(9),WAVER(15)
C
      IEU=NEL
      DO 5  IE=1,IEU
      QCOND(IE) = 0.
    5 Q(IE) = 0.
      DO 7 IS=1,NSEG
      QCONV(IS) = 0.
      QAB(IS) = 0.
      QRER(1,IS) = 0.
    7 QRER(2,IS) = 0.
      IF (KR-1) 10,30,20
   10 CALL SPECT (0,NTSPEC,TSPEC,NWLI,WAVE,QR,NWL,WAVEL,WAVEB,TIME,QRR)
      CALL FLUX (0,NOPT,NFLUX,TFLUX,FLUXT,QDMAX,TCUT,TIME,QRAD)
      CALL CONVEC (0,PO,TAM,VEL,TEMP,EL,XCON,HCONO,IE,TR,QCON)
      RETURN
C
   20 CALL SPECT (1,NTSPEC,TSPEC,NWLI,WAVE,QR,NWL,WAVEL,WAVEB,TIME,QRR)
      CALL FLUX (1,NOPT,NFLUX,TFLUX,FLUXT,QDMAX,TCUT,TIME,QRAD)
C
   30 ISU = NSEG
      DO 90  IS=1,ISU
      IE = JEL(IS)
      IF (IE.EQ.0) GO TO 50
C     INNER SURFACE.
      NM = IMAT(IE)
      TEL = TEMP(IE)
      IF (TEL.LT.TMELT(NM)) GO TO 42
      I = NAT(NM)
      EMISS = EMI(I,NM)
      GO TO 43
   42 CALL INT1Z (14,TEL,NAT(NM),TALF(1,NM),EMI(1,NM),EMISS)
   43 QRER(2,IS) = -(1.0E-14/3.0)*EL(IE)*EMISS*TEL**4
      Q(IE) = Q(IE) + QRER(2,IS)
   50 IE = IEL(IS)
      IF (IE.EQ.0) GO TO 90
C
C     CALCULATE CONVECTIVE HEAT FLOW
C
      CALL CONVEC (1,PO,TAM,VEL,TEMP,EL,XCON,HCONO,IE,TR,QCON)
      QCONV(IS) = QCON
      Q(IE) = Q(IE) + QCON
C
C     CALCULATE RADIATION FROM SURFACE ELEMENTS
C
      NM = IMAT(IE)
      TEL=TEMP(IE)
      IF (TEL.LT.TMELT(NM)) GO TO 62
      I=NAT(NM)
      EMISS=EMI(I,NM)
      GO TO 63
```

```
 62 CALL INT1Z (9,TEL,NAT(NM),TALF(1,NM),EMI(1,NM),EMISS)
 63 QPER(1,IS) = -(1.0E-14/3.0)*EL(IE)*EMISS*TEL**4
    Q(IE) = Q(IE) + QPER(1,IS)
    IF (KP.EQ.1) GO TO 90
C
C      OPAQUE PANELS AND SECTIONS.
C
    NM=IMAT(IE)
    DO 85  IWL=1,NWL
    IF (TEL.LT.TMELT(NM)) GO TO 83
    I=NAT(NM)
    ALFA=ALFAT(I,IWL,NM)
    GO TO 85
 83 CALL INT1Z (10,TEL,NAT(NM),TALF(1,NM),ALFAT(1,IWL,NM),ALFA)
 85 QAB(IS) = QAB(IS) + QRAD*QRR(IWL)*ALFA*EL(IE)
    Q(IE) = Q(IE) + QAB(IS)
 90 CONTINUE
    RETURN
    END
```

XHEAT

APPENDIX B

PROGRAM LISTING OF

APLOT

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```
      PROGRAM APLOT (OUTPUT,TAPE6=OUTPUT,TAPE8=514,TAPE40=514,PLOTS)
C     THIS PROGRAM PLOTS THE DATA GENERATED BY TRAP-ML AND STORED ON
C       FILES TAPE8.  THE OUTPUT PLOT TAPE IS TAPE39.
C     PROGRAM APLOT WAS WRITTEN BY KAMAN AVIDYNE, SEPT., 1973.
      COMMON /STORE/ DAT(200,6), IDD(20), QD, TC, IL1, TIM(600)
      COMMON/KACOM/NCPW,ICIN(2),ICOUT(1),INP(3),NGRAFS,NOGRAF,NCRT
      DIMENSION NPC(6),XMT(2),YMT(2),XT(3),YT(4),IT2(7),IT3(5),IPSS(6)
      DIMENSION IFMT(1)
      DATA  NX/10/, NY/13/
      DATA  XT/4HTIME,4H (SE,4HC)  /
      DATA  YT/4HTEMP,4H. (D,4HEG R,4H)    /
      DATA  NT1/40/, NT2/25/, NT3/22/
      DATA  IT2/4HPEAK,4H FLU,4HX, B,4HTU/I,4HN2/S,4HEC =,4H    /
      DATA  IT3/4HPULS,4HE DU,4HRATI,4HON, ,4HSEC ,4H=   /
      DATA  IFMT/4HF5.3/, IC/4/, IR/5/
      DATA  IPSS/1,3,5,6,4,2/
      DATA  AL/5.0/
      DATA  NDIMEN/200/
C
      CALL  PLOT (0.,0.,-3)
      CALL  FIRST (100)
C
   20 IPLOT = 0
      READ  (8)  (IDD(I),I=1,20), QD,TC,IL1,NOP,NSP
      IF  (EOF(8)) 900,40
   40 WRITE (6,7)
      IL = IL1 - 1
C
   50 IPLOT = IPLOT + 1
      I = IPLOT
      READ  (8) TIM(I),  (DAT(I,J),J=1,IL1)
      IF  (EOF(8)) 120,70
   70 WRITE (6,8)     TIM(I),(DAT(I,J),J=1,IL1)
      GO TO 50
C
  120 NC = IL1
      IPLOT = IPLOT - 1
C     ELIMINATE MELTED REGION.
      DO 200 J=1,NC
      DO 150 I=1,IPLOT
      N = I
      IF (DAT(I,J).EQ.0.0) GO TO 180
  150 CONTINUE
      NPC(J) = IPLOT
      GO TO 200
  180 NPC(J) = N-1
  200 CONTINUE
C     SCALE THE TABLE.
C
      N=IABS(NPC(1))
      CALL  KALE  (TIM,AL,N,1,XM,DX,DELX)
      CALL  KALE  (DAT,AL,N,1,YM,DY,DELY)
      IF(NC.EQ.1) GO TO 350
      XMIN  = XM
      XMAX  = XM+DX*AL
      YMIN  = YM
      YMAX  = YM+DY*AL
      NLOC  = 1
      DO 300 ISC=2,NC
      N=IABS(NPC(ISC))
      NLOC  = NLOC+NDIMEN
      CALL  KALE  (TIM,AL,N,1,XM,DX,DELX)
      CALL  KALE(DAT(NLOC),AL,N,1,YM,DY,DELY)
      TEST  = XM+DX*AL
      IF(XM.LT.XMIN) XMIN = XM
      IF(TEST.GT.XMAX)  XMAX = TEST
      TEST  = YM+DY*AL
      IF(YM.LT.YMIN) YMIN = YM
      IF  (TEST.GT.YMAX)  YMAX = TEST
  300 CONTINUE
      XMT(1) = XMIN
      XMT(2) = XMAX
      YMT(1) = YMIN
```

APLOT

```
      YMT(2) = YMAX
      CALL KALE(XMT,AL,2,1,XM,DX,DELX)
      CALL KALE(YMT,AL,2,1,YM,DY,DELY)
C
C     DRAW THE AXES.
C
  350 XAX = 0.0
      IF (YM.LT.0.0.AND.-YM/DY.LT.AL)  XAX=-YM/DY
      CALL KAXIS (0.0,XAX,XT,-NX,AL ,0.0,XM,DX,DELX,0)
      YAX=0.0
      IF (YM.LT.0.0.AND.-XM/DX.LT.AL) YAX=-XM/DX
      CALL KAXIS(YAX,0.0,YT,NY,AL,90.0,YM,DY,DELY,-1)
C
C     DRAW TITLES.
      H = 0.1
      CALL KASYM (0.3,5.5,H,IDD,0.0,NT1,3)
      CALL KASYM(0.8,5.3,H,IT2,0.0,NT2,3)
      CALL KANUM (999.0,5.3,H,DD,0.0,IFMT,IC,IR)
      IF (NOP.EQ.3) GO TO 400
      CALL KASYM (0.3,5.1,H, IT3,0.0,NT3,3)
      CALL KANUM (999.0,5.1,H,TC,0.0,IFMT,IC,IR)
C
C     PLOT EACH CURVE.
C
  400 NFR = IPLOT/5
      DO 500 I=1,NC
      K = NDIMEN*(I-1) + 1
      NP = NPC(I)
      IPS = IPSS(I)
      CALL KALINE (TIM(1),DAT(K),NP,XM,DX,YM,DY,NFR,IPS)
  500 WRITE (6,2) I
C
C     INDICATE MELT CONDITION.
C
      H = 0.1
      DO 600 J=1,NC
      IF (NPC(J).EQ.IPLOT) GO TO 600
      I = NPC(J)
      K = NDIMEN*(J-1) + I
      X = (TIM(I)-XM)/DX
      Y = (DAT(K)-YM)/DY - .5*H
      CALL KASYM (X,Y,H,IDUM,0.0,-7,3)
  600 CONTINUE
C
C     CHECK FOR LAST PLOT.
C
      IF (NOGRAF.EQ.1) GO TO 700
      WRITE (6,4) NOGRAF
      GO TO 800
  700 WRITE (6,5)
  800 NOGRAF=NOGRAF+1
C
C     ADVANCE TO NEXT FRAME.
C
      CALL KAVANS (AL+3.5,0.0)
      GO TO 20
C
C     CLOSE THE PLOTTING SYSTEM.
C
  900 NOGRAF = NOGRAF - 1
      WRITE (6,6) NOGRAF
      CALL PLOTE (NN)
      STOP
C
C     FORMAT STATEMENTS.
C
    2 FORMAT (6H CURVEI3,1X,7HPLOTTED/)
    4 FORMAT (5X,7H*******I3,1X,22HGRAPHS PLOTTED.*******)
    5 FORMAT (5X,34H*******FIRST GRAPH PLOTTED.*******)
    6 FORMAT (5X,7H*******I3,1X,37HGRAPHS PLOTTED, SYSTEM CLOSED.*******
     1)
    7 FORMAT (13H1DATA PLOTTED/)
    8 FORMAT (1H ,E15.6,5X,6E15.6)
```

```
C
      END
                                                    APLOT
```

```
      SUBROUTINE FIRST(M)
C
C     OPEN PLOT FILES FOR OFF-LINE PLOTS.
C
C     M = NUMBER OF GRAPHS TO BE PLOTTED.
C
      COMMON/KACOM/NCPW,ICIN(2),ICOUT(1),INP(3),NGRAFS,NOGRAF,NCRT
      DIMENSION I(2),K(3)
      DIMENSION PLOTID(3)
C
C....
      DATA I/4H(    ,4H4A1)/,J/4H(A4)/,K/4H(    ,4H18A4,4H)    /,L/4/
      DATA PLOTID/10H7299 BILL ,10HLEE PHONE ,10H 2721990
      N=IABS(M)
      XMAX=10*N
      YMAX=11.4
      CALL PLTID3(PLOTID,XMAX,YMAX,1.0)
C
C
C     NCRT = FLAG FOR TYPE OF PLOTTING.
C              REQUIRED AT SOME INSTALLATIONS FOR PROPER FILM ADVANCE
C              AND ORIGIN RESET.
C
C              0 = ORIGIN CONTROLLED BY USER.
C              1 = ORIGIN MOVED UP AND OVER 2.0 INCHES FOR USE WITH
C                  QUICK PLOT ROUTINES.
      NCRT=0
      IF (M.GT.0) NCRT=1
C
C
      IF (M.GT.0) CALL KAVANS (3.0,1.0)
C
C     IBM 360 - AVCO.
C     CALCOMP MODEL 890 CATHODE RAY TUBE PLOTTER.
C     MAXIMUM PLOT AREA WITHOUT DISTORTION = 7.5X7.5 INCHES.
C
      CALL IDFRM8('AVIDYNE ','A5',0,T,39)
C
      N=IABS(M)
C
C     IF M IS LESS THAN ZERO, USER IS EXPECTED TO ADVANCE
C     FILM BEYOND AVCO ID FRAME WITH
C
      CALL CALCMP(0.0,0.0,0,2)
C
C     IF USER CALLS KAVANS  ORIGIN WILL BE MOVED UP 1.05 INCHES,
C     AND RIGHT 1.25 INCHES - INTENSITY WILL BE CHANGED BY -5.
C
C
C     CHECK FOR QUICK PLOT OR USER PLOTTING.
C
C     MOVE PEN TO RIGHT OF I.D. FRAME AND SET INTENSITY
C     TO A LOWER LEVEL FOR FASTER BEAM MOVEMENT.
C
C     IF (M.GT.0) CALL KAVANS(1.05,1.25)
C
C     **********
C
C     SET COUNTERS.
C     NGRAFS = TOTAL NUMBER OF GRAPHS TO BE GENERATED.
C     NOGRAF = NUMBER OF NEXT GRAPH TO BE PLOTTED.
C
      NGRAFS=N
      NOGRAF=1
      NCPW=L
      ICIN(1)=I(1)
      ICIN(2)=I(2)
      ICOUT(1)=J
      INP(1)=K(1)
      INP(2)=K(2)
      INP(3)=K(3)
C
      WRITE (6,1)
    1 FORMAT (31H0PLOT ROUTINE APLOT INITIALIZED)
```

FIRST

```
C
      RETURN
      END                                                FIRST
```

```
      SUBROUTINE KALINE(XV,YV,N,XM,DX,YM,DY,K,KODES)
C
C     CALLING ARGUMENTS -
C
C     XV = X COORDINATES OF DATA POINTS TO BE PLOTTED. (REAL)
C     YV = Y COORDINATES OF DATA POINTS TO BE PLOTTED. (REAL)
C     N  = NUMBER OF DATA POINTS TO BE PLOTTED. (INTEGER)
C          A NEGATIVE N INDICATES A POINT BY POINT PLOT WITH
C          NO CONNECTING LINES.
C     XM = MINIMUM VALUE OF VARIABLE ON ABSCISSA. (REAL)
C     DX = SCALE FACTOR (UNITS/INCH) FOR ABSCISSA. (REAL)
C     YM = MINIMUM VALUE OF VARIABLE TO BE PLOTTED ON ORDINATE.(REAL)
C     DY = SCALE FACTOR (UNITS/INCH) OF VARIABLE TO BE PLOTTED ON
C          ORDINATE. (REAL)
C     K  = POSITIVE OR NEGATIVE CODE. (INTEGER)
C          IF POSITIVE, A SPECIAL CHARACTER FROM THE SYMBOL TABLE IS
C          TO BE PLOTTED. THE NUMBER OF THE CHARACTER IS GIVEN IN
C          KODES(1).
C
C          IF NEGATIVE, THE USER SUPPLIES THE PLOT CODE FOR HIS
C          OWN SPECIAL CHARACTER IN KODES.
C          KODES(1) = NUMBER OF WORDS DESCRIBING SYMBOL.
C          KODES(2) = START OF SYMBOL.
C
C          IF K = 0, (1) NO SPECIAL SYMBOL IS TO BE USED, AND
C                    (2) EVERY POINT IN THE TABLE IS TO BE PLOTTED.
C          MAGNITUDE OF K INDICATES POINTS IN TABLE TO BE PLOTTED.
C          K = 1, EVERY POINT.
C          K = 2, EVERY SECOND POINT.
C          K = 3, EVERY THIRD POINT.
C          ETC.
C
      DIMENSION XV(1),YV(1),KODES(1)
      IF (N.EQ.0) RETURN
C
C     CHECK FOR CONTINUOUS LINE.
C
      IF(N.LT.0) GO TO 20
C
C     DRAW CONTINUOUS CURVE.
C
      X=(XV(1)-XM)/DX
      Y=(YV(1)-YM)/DY
      CALL  PLOT(X,Y,3)
      DO 10 I=1,N
      X=(XV(I)-XM)/DX
      Y=(YV(I)-YM)/DY
   10 CALL  PLOT(X,Y,2)
C
C     CHECK FOR SPECIAL SYMBOLS.
C
      IF (K.EQ.0) GO TO 50
C
C     MOVE PEN TO FIRST POINT.
C
   20 X=(XV(1)-XM)/DX
      Y=(YV(1)-YM)/DY
      CALL  PLOT(X,Y,3)
      M=IABS(N)
C
C     CHECK FOR USER SUPPLIED CODE.
C
      IF (K.LT.0) GO TO 60
      L=K
      IK=1
      KODE=-KODES(1)
   30 IL = L
      DO 40 I = IL,M,L
      X=(XV(I)-XM)/DX
      Y=(YV(I)-YM)/DY
   40 CALL  KASYM(X,Y,0.1,KODES(IK),0.0,KODE,3)
C
C     LIFT PEN
```

KALINE

```
C
   50 CALL PLOT(X,Y,3)
      RETURN
C
C     USER SUPPLIED CODE.
C
   60 KODE=-20-KODES(1)
      IK=2
      L=-5
      GO TO 30
      END
```

KALINE

```
      SUBROUTINE KALE(D,AL,NP,J,AMIN,DA,DEL)
C
C     SUBROUTINE KALE PROVIDES SCALING INFORMATION FOR
C     THE AXIS ROUTINE KAXIS.
C
C     CALLING ARGUMENTS -
C
C     INPUT -
C
C     D     = ARRAY OF DATA POINTS TO BE EXAMINED. (REAL)
C     AL    = AXIS LENGTH, INCHES. (REAL)
C     NP    = NUMBER OF POINTS TO BE SCANNED IN ARRAY. (INTEGER)
C     J     = JUMP CODE WHOSE MAGNITUDE DETERMINES
C             THE DATA TO BE SCALED.
C             J = 1, USE EVERY POINT.
C             J = 2, USE EVERY SECOND POINT.
C             J = 3, USE EVERY THRID POINT.
C             ETC.
C             (INTEGER)
C
C     OUTPUT -
C
C     AMIN  = STARTING VALUE FOR VARIABLE ON AXIS. (REAL)
C     DA    = SCALE FACTOR, UNITS PER INCH, TO BE USED ON AXIS. (REAL)
C     DEL   = UNITS PER TIC MARK. (REAL)
C             ALLOWABLE DIVISIONS - 1.0,2.0,5.0 * POWER OF TEN.
C
C     CAUTION - WHEN PLOTTING ON GRAPH PAPER, PLEASE NOTE THAT
C               THE NUMBER OF MAJOR TIC MARKS IS DETERMINED BY THE DATA.
C               UNLIKE OTHER PLOT PACKAGES (SUCH AS CALCOMP, ETC.)
C               THIS ROUTINE WILL NOT ALWAYS PRODUCE ONE MAJOR
C               TIC MARK PER INCH.
C
      DIMENSION D(1)
C
C     OBTAIN TOTAL NUMBER OF POINTS IN ARRAY, N.
C
      N=NP*J
C
C     AMIN = MINIMUM VALUE OF DATA IN ARRAY.
C     AMAX = MAXIMUM VALUE OF DATA IN ARRAY.
      AMIN=D(1)
      AMAX=AMIN
      DO 20 I=1,N,J
C
C     T = TEST VALUE.
C
      T=D(I)
      IF (AMIN.LT.T) GO TO 10
      AMIN=T
      GO TO 20
   10 IF (AMAX.GT.T) GO TO 20
      AMAX=T
   20 CONTINUE
      IF (AMAX.EQ.AMIN) AMAX=1.001*AMIN
      IF (AMAX.LT.AMIN) AMAX=0.99*AMIN
      IF (AMAX.NE.AMIN) GO TO 25
      WRITE (6,1) AL,NP
    1 FORMAT (64H1***POSSIBLE ERROR DETECTED BY KALE. DATA TO BE SCALED
     1ALL ZERO. /15H AXIS LENGTH = E13.5,1H,I6,8H POINTS.)
C
C     SPECIAL DEBUG OUTPUT FOR CDC 6600.
C
      I=LOCF(D)
      WRITE (6,2) I
    2 FORMAT (28H STARTING ADDRESS OF DATA = O8/)
C
C
      AMAX=1.0
C
C     MINIMUM AND MAXIMUM SHOULD FALL ON TIC MARKS.
C     ALLOWABLE TIC MARKS = 1, 2, OR 5.
C     R = RANGE.
```

KALE

```
C
   25 R=AMAX-AMIN
      ROL=R/AL
      DUM=ALOG10(ROL)
      I=INT(DUM)
      ROL=ROL/(10.0**I)
      IF (ROL.GT.1.0) GO TO 30
      DEL=10.0**I
      GO TO 50
   30 IF (ROL.GT.2.0) GO TO 40
      DEL=2.0*10.0**I
      GO TO 50
   40 IF (ROL.GT.5.0) GO TO 45
      DEL=5.0*10.0**I
      GO TO 50
   45 DEL=10.0**(I+1)
   50 DUM=AMIN/DEL
      I=INT(DUM)
      IF (FLOAT(I).GT.DUM) I=I-1
      AMIN=FLOAT(I)*DEL
      R=AMAX-AMIN
      DUM = 1.0001*DEL*AL + AMIN
      IF(AMAX.LT.DUM) AMAX = DUM
C
C     NT = NUMBER OF TIC MARKS BEYOND STARTING VALUE.
C
      NT=INT(R/DEL-0.0001)+1
      IF (NT.GT.INT(AL)) GO TO 25
      DA=DEL*FLOAT(NT)/AL
      RETURN
      END
```

KALE

```
      SUBROUTINE KANUM(X,Y,H,F,ANGLE,IFMT,NC,NR)
C
C     SUBROUTINE KANUM PLOTS NUMBERS ACCORDING TO FORMAT IFMT.
C
C
C     CALLING ARGUMENTS -
C
C     X,Y    = COORDINATES OF LOWER LEFT CORNOR OF NUMBER
C              TO BE PLOTTED, IN INCHES, FROM THE ORIGIN. (REAL)
C     H      = HEIGHT, IN INCHES, OF PLOTTED NUMBER.
C     F      = NUMBER TO BE PLOTTED.
C              CAN BE EITHER INTEGER OR DECIMAL.
C     ANGLE  = ANGULAR ORIENTATION, IN DEGREES, OF PLOTTED NUMBER
C              MEASURED COUNTERCLOCKWISE FROM HORIZONTAL AXIS.(REAL)
C     IFMT   = FORMAT UNDER WHICH NUMBER, F, IS TO BE WRITTEN.
C              ANY ALLOWABLE FORTRAN FORMAT THAT CORRESPONDS
C              IN TYPE TO F. (HOLLERITH)
C     NC     = NUMBER OF CHARACTERS IN FORMAT, IFMT. (INTEGER)
C     NR     = NUMBER OF CHARACTERS RESULTING FROM FORMAT. (E.G. E16.4
C               RESULTS IN 16 CHARACTERS.) (INTEGER)
C
      COMMON/KACOM/NCPW,ICIN(2),ICOUT(1),INP(3),NGRAFS,NOGRAF,NCRT
      DIMENSION NFMT(18),IFMT(1),NOUT(18)
      DATA  NFMT(1)/4H(    /,NFMT(18)/4H)    /
C
      IF (NC.EQ.0) GO TO 20
C
C     N = NUMBER OF ALPHAMERIC WORDS IN IFMT.
C
      N=NC/NCPW
      IF (N*NCPW.LT.NC)  N=N+1
      J=2
C
C     FILL FORMAT ARRAY.
C
      DO 10 I=1,N
      NFMT(J)=IFMT(I)
   10 J=J+1
      IF (J.LT.18) NFMT(J)=NFMT(18)
C
C     CONVERT TO ALPHAMERIC.
C
      WRITE (40,NFMT) F
      REWIND 40
      N=NR/NCPW
      IF (N*NCPW.LT.NR)N=N+1
      READ  (40,INP)  (NOUT(I),I=1,N)
      REWIND 40
C
C     PLOT CODE.
C
      CALL  KASYM(X,Y,H,NOUT,ANGLE,NR,3)
   20 RETURN
      END
```

KANUM

```
SUBROUTINE KASYM(X3,Y3,HEIGHT,IBCD,ANGLE,NCHAR,IPENC)

SUBROUTINE KASYM  DRAWS ALPHNUMERIC INFORMATION
AND SPECIAL SYMBOLS AT ANY ANGLE AND ANY SIZE
ON THE PLOTTING AREA.

IN ITS STANDARD FORM SYMBOL IS USED TO PRINT TEXT
MATERIAL ALONG AXES, AND TITLE GRAPHS. THE LETTERS
A THROUGH Z, DIGITS 0 THROUGH 9 AND ALL OTHER STANDARD
FORTRAN CHARACTERS ARE AVAILABLE.

IN AN ALTERNATE FORM, IT WILL PLOT A CENTERED SYMBOL
FROM THE SPECIAL SYMBOL TABLE, OR A USER SUPPLIED SYMBOL.

THE ARGUMENT NCHAR CONTROLS THE FORM TO BE USED.

ARGUMENT LIST -
X3, Y3 = COORDINATES,IN INCHES,OF EITHER
         (1) THE LOWER LEFT CORNER OF THE
             FIRST CHARACTER OF STANDARD TEXT TO
             BE PRINTED - OR -
         (2) THE CENTER OF THE SPECIAL SYMBOL
             TO BE PLOTTED.
HEIGHT = HEIGHT, IN EITHER INCHES OR CENTIMETERS,
         OF THE TEXT CHARACTERS, OR SPECIAL SYMBOLS
         TO BE PLOTTED.
         IF HEIGHT IS GREATER THAN 0.0, THE UNITS
         ARE ASSUMED TO BE IN INCHES.
         IF HEIGHT IS LESS THAN 0.0, THE UNITS
         ARE ASSUMED TO BE IN CENTIMETERS.

IBCD   = TEXT MATERIAL TO BE PRINTED, OR
         SPECIAL SYMBOL CODE, DEPENDING UPON
         THE VALUE OF NCHAR.
         STANDARD ALPHANUMERIC TEXT (BCD OR
         A-TYPE FORMAT) SHOULD BE LEFT-JUSTIFIED
         AND CONTIGUOUS IN
         (1) A SINGLE VARIABLE,
         (2) AN ARRAY, OR
         (3) A HOLLERITH LITERAL (IF THE COMPILER PERMITS).

         SPECIAL SYMBOL CODES SHOULD BE INTEGER FORMAT.

ANGLE  = ANGULAR ORIENTATION, IN DEGREES, AT WHICH CHARACTER
         LINE IS TO BE PRINTED. POSITIVE VALUES ARE MEASURED
         COUNTERCLOCKWISE FROM THE HORIZONTAL X-AXIS, AND
         NEGATIVE VALUES ARE MEASURED CLOCKWISE.

NCHAR  = CONTROL CONSTANT FOR TYPE OF MATERIAL TO BE
         PRINTED ON PLOT.

         A POSITIVE NCHAR INDICATES STANDARD
         ALPHANUMERIC TEXT IS TO BE PRINTED. NCHAR
         IS THE NUMBER OF CHARACTERS TO BE PRINTED.

         A NEGATIVE NCHAR INDICATES A SPECIAL
         CENTERED SYMBOL IS TO BE PLOTTED. IF THE
         ABSOLUTE VALUE OF NCHAR IS BETWEEN 1 AND 14,
         A SPECIAL SYMBOL FROM THE TABLE IS PRINTED.
         IF THE ABSOLUTE VALUE OF NCHAR IS GREATER
         THAN 14, THE USER SUPPLIES HIS OWN
         SPECIAL SYMBOL IN IBCD.
         IF MORE THAN TWO WORDS ARE REQUIRED FOR THE
         DEFINITION OF THE NEW SYMBOL, EXPAND
         THE DIMENSION OF NODE.
         THE DIMENSION OF THE NEW SYMBOL IN THE
         CALLING PROGRAM IN NOW ASSUMED TO BE TWO.

IPENC  = PEN CODE.
       = 2, PEN DOWN DURING MOVE TO (X3,Y3).
       = 3, PEN UP DURING MOVE TO (X3,Y3).
```

```
C       NODAL CODES FOR STANDARD FORTRAN CHARACTERS ARE
C       CONTAINED IN NORMAL, AND SPECIAL SYMBOLS IN NODES.
C       NSYM IS THE NUMBER OF SPECIAL SYMBOL CODES IN NODES.
C
        COMMON/KACOM/NORW,ICIN(2),ICOUT(1),INP(3),NGRAFS,NOGRAF,NCRT
        DIMENSION ICHARS(10)
        DIMENSION IBCD(1),IN(14),INORM(51),NODES(90),NORMAL(205)
        DIMENSION NORM(51)
        DATA XSAVE/0.0/,YSAVE/0.0/
C
        DATA NORMAL/5313,1757,5344,5203,0757,
       11744,6253,1322,2110,6657,2726,4400,6253,1322,2110,
       25010,2526,1757,6644,6360,2040,1317,4400,2363,6010,
       32526,1757,6644,2213,5362,6657,1726,2510,0055,6644,
       46253,2301,0744,5065,6657,1726,2510,5061,6253,1322,
       52110,4400,2110,5061,6253,1322,2617,5766,4400,5010,
       65044,4400,0607,5756,0644,2363,6101,6167,4400,5313,
       70307,5717,4400,2213,5362,6657,1726,2000,0544,6366,
       85717,2623,4400,6763,1322,2110,6000,2744,2363,6000,
       95057,2744,0206,0050,1044,1303,5256,0717,4400,5303,
       11216,0757,4400,5121,4025,6544,6263,2322,4003,0744,
       26763,0723,2744,2213,5362,6150,1025,2617,5765,4400,
       36761,0321,2725,6544,6723,4400,2617,5766,6253,1322,
       44400,6367,2726,4400,5362,6657,1726,2213,5340,2357,
       54400,6763,2723,4400,6327,4023,6744,6300,2340,0007,
       64400,6323,6727,4050,1044,6010,2122,1363,6717,2625,1044,6763,
       71322,2617,6744,6367,6020,2723,4400,6667,0703,6323,4400,6367,
       86523,5027,4400,6010,2122,1363,6744,1726,2213,5362,6657,1740,
       91627,4400,6307,2344,6357,0317,2344,6623,4003,0740,6327,4400,
       11606,0515,1607,4400,2213,5362,6150,1025,2617,5756,4003,0744/
        DATA NORM /1H0,1H1,1H2,1H3,1H4,1H5,1H6,
       11H7,1H8,1H9,1H-,1H ,1H.,1HF,1HI,1HG,1HU,1HR,1HE,
       21H+,1H(,1H),1H=,1HT,1HM,1HS,1HA,1H/,1HC,1HL,1HO,
       31HN,1HX,1HY,1HZ,1HB,1HD,1HH,1HJ,1HK,1HP,1HQ,1HV,
       41HW,1H*,1H,,1H$,1H%,1H<,1H&,1H#/,NNORM/51/
        DATA INORM/1,4,7,13,20,24,29,36,39,
       148,55,57,58,61,65,69,75,79,84,88,91,95,99,
       2102,106,109,116,120,122,127,130,137,140,143,147,
       3151,157,161,165,169,173,177,184,186,189,194,198,91,95,88,99/
        DATA NODES/4033,7377,3733,4044,4053,
       17175,5717,3531,1353,4044,4003,7737,0340,4400,0003,
       20700,7030,0040,4400,0073,3700,3377,0040,4400,4003,
       37007,3003,4044,0007,0370,3003,4044,0077,3373,3700,
       44044,4073,3377,3700,6020,0040,4400,0007,0073,0033,
       50040,4400,4073,6266,7766,2637,2622,3322,6240,4400,
       60003,0700,3377,0073,3700,4044,0033,7337,7700,4044,
       70007,0300,4044/,NNODES/68/
        DATA IN/1,5,11,15,20,25,29,33,37,43,48,56,
       162,66/,NSYM/14/
C
        DATA LIFT/40/,NEXT/44/
        DATA PIO180/1.745329252E-02/
C
C       CHECK FOR EMPTY RUN.
C
        IF (NCHAR.EQ.0) RETURN
        X1=X3
        IF (X3.EQ.999.0) X1=XSAVE
        Y1=Y3
        IF (Y3.EQ.999.0) Y1=YSAVE
C
C       MOVE PEN TO (X1,Y1).
C
        CALL PLOT (X1,Y1,IPENC)
C
C       CHANGE ANGLE TO RADIANS.
C
        T=ANGLE*PIO180
C
C       INITIALIZE.
C
        SINT=SIN(T)
        COST=COS(T)
```

KASYM

```
      H=HEIGHT
C
C     CHANGE CENTIMETERS TO INCHES IF NECESSARY.
C
      IF (H.LT.0.0) H=-H*2.54
C
C     DEL = DISTANCE IN INCHES BETWEEN NODES.
C
      DEL=H/7.0
      DELC=DEL*COST
      DELS=DEL*SINT
      ISTART=1
C
C     DETERMINE TYPE OF CHARACTERS TO BE PLOTTED.
C
      IF (NCHAR.GT.0) GO TO 70
C
C     SPECIAL SYMBOL.
C
      N=-NCHAR
      X2=X1+H*COST
      Y2=Y1+H*SINT
      IF (N.GT.NSYM) GO TO 60
C
C     SYMBOL IS CONTAINED IN TABLE.
C
      INDEX=IN(N)
   10 ICHAR=NODES(INDEX)
      IPART=1
C
C     PLOT NODES.
C
   20 NODE=ICHAR/100
      IF (IPART.EQ.2) NODE=ICHAR-100*NODE
C
C     IF NODE = 40, LIFT PEN AND GO BACK FOR ANOTHER POINT.
C
      IF (NODE.EQ.LIFT) GO TO 50
C
C     IF NODE = 44, END OF THIS SYMBOL.
C
      IF (NODE.EQ.NEXT) GO TO 170
C
C     SEPARATE NODE INTO (X,Y) COORDINATES.
C
      IX=NODE/10
      IY=NODE-10*IX
      IF (IX.GT.4) IX=4-IX
      IF (IY.GT.4) IY=4-IY
C
C     OBTAIN COORDINATES OF NODE.
C
      X=X1+DELC*FLOAT(IX)-DELS*FLOAT(IY)
      Y=Y1+DELC*FLOAT(IY)+DELS*FLOAT(IX)
C
C     PLOT POINT.
C
      IF (ISTART.EQ.1) CALL PLOT(X,Y,3)
      ISTART=ISTART+1
      IPEN=2
   30 CALL PLOT (X,Y,IPEN)
C
C     OBTAIN NEXT POINT.
C
      IPART=IPART+1
      IF (IPART.LE.2) GO TO 20
      INDEX=INDEX+1
      GO TO 10
   50 IPEN=3
      ISTART=1
      X=X1
      Y=Y1
      GO TO 30
```

KASYM

```
C
C     SPECIAL SYMBOL - USER SUPPLIED.
C
   60 INDEX=NNODES+1
      J=N-20
      DO 65 I=1,J
      K=NNODES+I
   65 NODES(K)=IBCD(I)
C
      GO TO 10
C
C     STANDARD FORTRAN CODE.
C
   70 NW=1
      NC=1
C
C     SHIFT TO CENTER OF GRID.
C
      X2=X1+3.0*(DELC-DELS)
      Y2=Y1+3.0*(DELC+DELS)
      DC7=7.0*DELC
      DS7=7.0*DELS
   80 LETTER=1
      IPART = 1
C
C     OBTAIN CODE OF CHARACTER.
C
      WRITE (40,ICOUT) IBCD(NW)
      REWIND 40
      READ (40,ICIN) (ICHARS(I),I=1,NCPW)
      REWIND 40
   90 NODE = ICHARS(LETTER)
      DO 95 ITEN = 1,NNORM
      IF (NODE.EQ.NORM(ITEN)) GO TO 96
   95 CONTINUE
      WRITE (6,1) NODE,IBCD(NW)
    1 FORMAT (66H0***WARNING***. NON-STANDARD FORTRAN SYMBOL ENCOUNTERED
     1 BY KASYM. A1,2X,A10/)
      RETURN
C
C     OBTAIN STARTING POINT IN TABLE.
C
   96 INDEX = INORM(ITEN)
C
C     OBTAIN CHARACTER CODE FROM TABLE.
C
  100 ICHAR=NORMAL(INDEX)
      IPART = 1
C
C     PLOT NODE.
C
  110 NODE = ICHAR/100
      IF (IPART.EQ.2) NODE=ICHAR-100*NODE
C
C     IF NODE = 40, LIFT PEN AND GO BACK FOR ANOTHER POINT.
C
      IF (NODE.EQ.LIFT) GO TO 140
C
C     IF NODE = 44, END OF THIS CHARACTER.
C
      IF (NODE.EQ.NEXT) GO TO 150
C
C     SEPARATE NODE INTO (X,Y) COORDINATES.
C
      IX = NODE/10
      IY = NODE-10*IX
      IF(IY.GT.4) IX = 4-IX
      IF (IY.GT.4) IY = 4-IY
C
C     PLOT NODE.
C
      X=X2+DELC*FLOAT(IX)-DELS*FLOAT(IY)
      Y=Y2+DELC*FLOAT(IY)+DELS*FLOAT(IX)
```

KASYM

```
      IF (ISTART.EQ.1) CALL PLOT(X,Y,3)
      ISTART=ISTART+1
      IPEN=2
  120 CALL PLOT (X,Y,IPEN)
C
C     OBTAIN NEXT POINT.
C
      IPART = IPART+1
      IF (IPART.LE.2) GO TO 110
      INDEX=INDEX+1
      GO TO 100
  140 IPEN=3
      X=X2
      Y=Y2
      ISTART=1
      GO TO 120
C
C     NEXT CHARACTER.
C
  150 LETTER=LETTER+1
      CALL PLOT(X2,Y2,3)
      NC=NC+1
      ISTART=1
      X2=X2+DC7
      Y2=Y2+DS7
      IF (NC.GT.NCHAR) GO TO 160
      IF (LETTER.LE.NCPW) GO TO 90
C
C     INCREASE WORD COUNT.
C
      NW=NW+1
      GO TO 80
C
C     RESET PEN AT NEW (X2,Y2).
C
  160 XSAVE=X2 -3.0*(DELC -DELS)
      YSAVE=Y2 -3.0*(DELC +DELS)
  165 CALL PLOT(X1,Y1,3)
      RETURN
  170 XSAVE=X2
      YSAVE=Y2
      GO TO 165
      END
```

KASYM

```
      SUBROUTINE KAVANS(X,Y)
C
C     SUBROUTINE KAVANS ADVANCES THE FILM TO THE NEXT FRAME, AND
C     RESETS THE LOGICAL ORIGIN PREVIOUSLY DEFINED.
C
C     A CALL WITH EITHER X OR Y = 999.0 WILL RESULT IN THE
C     PREVIOUSLY DEFINED VALUES OF X AND Y BEING USED.
C
      DATA XSAVE/0.0/,YSAVE/0.0/
C
      X1=X
      IF (X1.EQ.999.0) X1=XSAVE
      XSAVE=X1
      Y1=Y
      IF (Y1.EQ.999.0) Y1=YSAVE
      YSAVE=Y1
C
C     FOR CALCOMP PEN PLOTTERS, USE
C
C     CALL PLOT(X1,Y1,-3)
      CALL PLOT(X1,Y1,-3)
C
C     FOR CATHODE RAY TUBE PLOTTERS, USE
C
C     CALL CALCMP(0.0,0.0,0000,2)
C     CALL CALCMP(X1,Y1,-6,3)
C
C     TO ADVANCE THE FILM, AND
C     TO RESET THE LOGICAL ORIGIN.
C
      RETURN
C
      END
```

KAVANS

```
      SUBROUTINE KAXIS(X,Y,LABEL,NC,AL,ANGLE,AMIN,DA,DEL,ITURN)
C
C     SUBROUTINE KAXIS DRAWS A LABELED AXIS.
C
C     CALLING ARGUMENTS -
C     X     = X-COORDINATE IN INCHES OF THE START OF THE ORIGIN. (REAL)
C     Y     = Y-COORDINATE IN INCHES OF THE START OF THE ORIGIN. (REAL)
C     LABEL = ALPHAMERIC TEXT TO BE PRINTED ALONG AXIS. (HOLLERITH)
C     NC    = NUMBER OF CHARACTERS IN LABEL (INCLUDING ALL BLANKS).
C             A POSITIVE VALUE WILL PLACE THE TITLE ON THE
C             COUNTERCLOCKWISE SIDE OF THE AXIS. USUAL Y-AXIS.
C             A NEGATIVE VALUE WILL PLACE THE LABEL ON THE CLOCKWISE
C             SIDE OF THE AXIS, USUAL X-AXIS.
C             (INTEGER)
C     AL    = LENGTH OF AXIS IN INCHES. (REAL)
C     ANGLE = ANGULAR ORIENTATION OF AXIS, DEGREES.
C             0 DEGREES = HORIZONTAL TO RIGHT, POSITIVE ANGLES
C             ARE MEASURED COUNTERCLOCKWISE.
C             (REAL)
C     AMIN  = MINIMUM VALUE OF VARIABLE ON AXIS.
C             VALUE RETURNED BY KALE. (REAL)
C     DA    = SCALE FACTOR, UNITS/INCH, OF VARIABLE ALONG AXIS. (REAL)
C     DEL   = UNITS/TIC MARK, RETURNED BY KALE. (REAL)
C     ITURN = NUMBER OF 90 DEGREE ROTATION OF NUMBERS INDICATING
C             VALUE OF MAJOR TIC MARKS. (INTEGER)
C
      COMMON/KACOM/NCPW,ICIN(2),ICOUT(1),INP(3),NGRAFS,NOGRAF,NCRT
      DIMENSION LABEL(1),JFMT(12),IFMT(3)
      DATA JFMT/4HF6.1,4HF6.2,4HF6.3,2HI2  ,4H,1HX,4H2H10,2HI3  ,
     12HI5,2HI6,2HI4,2HI3,2HI1/
C
C     HGTNUM = HEIGHT OF NUMBERS ALONG AXIS, INCHES.
C     DSTO   = DISTANCE BETWEEN AXIS AND TOP OF NUMBERS, AND BETWEEN
C            NUMBERS AND AXIS LABEL.
C     HGTSYM = MAXIMUM ALLOWABLE HEIGHT OF SYMBOLS IN AXIS TITLE.
C            INCHES.
C
      DATA HGTNUM/0.100/,DSTO/0.09/,HGTSYM/0.130/
C
C
C     CENTER = NUMBER CENTERING VARIABLE.
C
C     PROBLEM -
C
C     SOME SYSTEMS RIGHT JUSTIFY NUMBERS WRITTEN UNDER FORMAT
C     STATEMENTS. OTHERS LEFT JUSTIFY THESE NUMBERS. THUS, ON SOME
C     MACHINES THE MAJOR TIC MARK VALUES MAY BE SHIFTED EITHER
C     LEFT OR RIGHT OF WHERE THEY SHOULD BE.
C
C     SOLUTION -
C
C     CENTER PERMITS CENTERING NUMBERS FOR PARTICULAR SYSTEM IN USE.
C
C     CENTER = 0.0, LEFT SIDE OF NUMBER WILL LINE UP WITH MAJOR TIC MARK
C     CENTER = 1.0, RIGHT SIDE OF NUMBER WILL LINE UP WITH MAJOR TIC MAR
C     CENTER = 0.5, MIDDLE OF NUMBER (AS FORMATTED) WILL LINE UP WITH
C                   MAJOR TIC MARK. THUS, WITH AN I5 FORMAT,
C                   THE THIRD SPACE WILL LINE UP WITH THE TIC MARK.
C
      DATA CENTER/0.5/
C
      SIDE=1.0
      IF (NC.LT.0) SIDE=-1.0
      DST=DSTO
      IF (SIDE.EQ.-1.0.AND.ITURN.EQ.0) DST=DST+HGTNUM
      CIT=0.0
      IF (ITURN.NE.0) CIT=-1.0
      XOR=1.0
      IF (SIDE.EQ.FLOAT(ITURN)) XOR=0.0
      THETA=ANGLE*0.0174532952
      SINT=SIN(THETA)
      COST=COS(THETA)
      T=ANGLE+FLOAT(ITURN)*90.0
```

```
      TN=T*0.0174532952
      CTN=COS(TN)
      STN=SIN(TN)
C
C     NUMBER ORIENTATION CORRECTIONS.
C
      CON=SIDE*XOR*SINT*CIT-CENTER*COST*(CIT+1.0)
      CON1=SIDE*XOR*COST*CIT+CENTER*SINT*(CIT+1.0)
C
C     PLOT MAJOR TIC MARKS.
C     R  = RANGE OF VARIABLE.
C     NT = NUMBER OF TIC MARKS.
C
      AMAX=AMIN+AL*DA
      R=AMAX-AMIN
      NT=INT (R/DEL+0.1)
      XB=X
      YB=Y
C
C     TIC HEIGHT = 0.1 INCHES.
C
      XA=X+0.1*SIDE*SINT
      YA=Y-0.1*SIDE*COST
C
C     XC = CONSTANT INCREMENT ALONG X AXIS.
C     YC = CONSTANT INCREMENT ALONG Y AXIS.
C
      XC=DEL*COST/DA
      YC=DEL*SINT/DA
      CALL  PLOT(XA,YA.3)
      CALL  PLOT(XA,YA.2)
      J=1
      NTM=NT
    5 DO 10 I=1,NTM
      CALL  PLOT(XB,YB,2)
      XB=XB+XC
      YB=YB+YC
      CALL  PLOT(XB,YB,2)
      XA=XA+XC
      YA=YA+YC
   10 CALL  PLOT(XA,YA,2)
C
C     PLOT MINOR TIC MARKS, 10/INTERVAL.
C
      NTM=10*NT
      IF (J.EQ.2) GO TO 20
      J=2
      XA=XB+0.05*SIDE*SINT
      YA=YB-0.05*SIDE*COST
      XC=-0.1*XC
      YC=-0.1*YC
      GO TO 5
   20 XC=-10.0*XC
      YC=-10.0*YC
C
C     WRITE VALUE AT TIC MARKS.
C
      NT=NT+1
      A=ABS(DEL)
      IF (A.LT.1.0.OR.A.GE.10000.0) GO TO 60
C
C     INTEGER FORMAT.
C
      I=INT(AMIN)
      J=INT(DEL)
      IC=2
      IR=5
      IFMT(1)=JFMT(8)
      IF (AMIN.NE.-10000.0) GO TO 24
      IR=6
      IFMT(1)=JFMT(9)
      GO TO 25
   24 B=ABS(AMAX)
```

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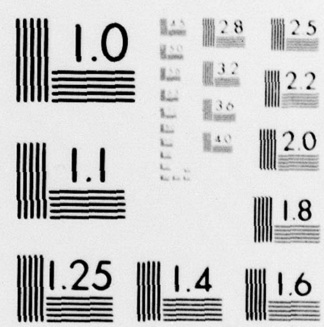

MICROCOPY RESOLUTION TEST CHART
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```
      IF (B.LT.ABS(AMIN)) B=ABS(AMIN)
      B=B+0.1
      IF (B.GE.1000.) GO TO 25
      IR=4
      IFMT(1)=JFMT(10)
      IF (B.GE.100.0) GO TO 25
      IR=3
      IFMT(1)=JFMT(11)
      IF (AMIN.LT.0.0 .OR. DEL.LT.0.0) GO TO 25
      IR=2
      IFMT(1)=JFMT(4)
      IF (B.GE.10.0) GO TO 25
      IFMT(1)=JFMT(12)
      IR=1
   25 FIR=FLOAT(IR)*HGTNUM
      XB=X-SIDE*DST*SINT+FIR*CON
      YB=Y+SIDE*DST*COST-FIR*CON1
      DO 30 II=1,NT
      CALL KANUM(XB,YB,HGTNUM,I,T,IFMT,IC,IR)
      XB=XB+XC
      YB=YB+YC
   30 I=I+J
   40 IF (NC.EQ.0) GO TO 45
C
C     LABEL AXIS.
C
      S=FLOAT(NC)*SIDE+1.0
      H=AL/S
      IF (H.GT.HGTSYM) H=HGTSYM
      TD=H*S
      XB=X+0.5*(AL-TD)*COST-SIDE*SINT*(HGTNUM+2.0*DST0+0.5*(1.0-SIDE)*H)
      IF (ITURN.NE.0) XB=XB-(FIR+DST0)*CTN
      YB=Y+0.5*(AL-TD)*SINT+SIDE*COST*(HGTNUM+2.0*DST0+0.5*(1.0-SIDE)*H)
      IF (ITURN.NE.0) YB=YB-(FIR+DST0)*STN
      I=IABS(NC)
      CALL KASYM(XB,YB,H,LABEL,ANGLE,I,3)
   45 RETURN
C
C     DECIMAL NOTATION.
C
   50 B=ALOG10(A)
      IF (B.GT.0.0) B=B+0.02
      I=INT (B-0.01)
      IF (I.GT.0.OR.I.LT.-2) GO TO 80
      IFMT(1)=JFMT(3)
      IF (B.LE.-1.0) IFMT(1)=JFMT(2)
      IC=4
      IR=6
      A=AMIN
      FIR=6.0*HGTNUM
      XB=X-SIDE*DST*SINT+FIR*CON
      YB=Y+SIDE*DST*COST-FIR*CON1
   70 DO 72 I=1,NT
      CALL KANUM(XB,YB,HGTNUM,A,T,IFMT,IC,IR)
      XB=XB+XC
      YB=YB+YC
   72 A=A+DEL
      GO TO 40
C
C     EXPONENTIAL FORMAT.
C
   80 A=10.0**I
      AM=AMIN/A
      ADA=DEL/A
      NT=NT-1
      IF (ADA.GE.0.01) GO TO 90
      I=I-1
      GO TO 80
   90 IFMT(1)=JFMT(2)
      IF (ADA.GE.1.0) IFMT(1)=JFMT(1)
      IC=4
      IR=6
```

```
      FIR=6.0*HGTNUM
      XB=X-SIDE*DST*SINT+FIR*CON
      YB=Y+SIDE*DST*COST-FIR*CON1
  100 DO 110 J=1,NT
      CALL KANUM(XB,YB,HGTNUM,AM,T ,IFMT,IC,IR)
      XB=XB+XC
      YB=YB+YC
  110 AM=AM+ADA
      IFMT(1)=JFMT(2)
      IFMT(2)=JFMT(5)
      IFMT(3)=JFMT(6)
      IC=12
      IR=13
      XB=XB-0.4*CTN
      YB=YB-0.4*STN
  115 CALL KANUM(XB,YB,HGTNUM,AM,T,IFMT,IC,IR)
C
C     INSERT EXPONENT.
C
      XB=XB+9.0*HGTNUM*CTN-HGTNUM*STN
      YB=YB+9.0*HGTNUM*STN+HGTNUM*CTN
C
C     9.0 = 6 CHARACTERS IN NUMBER + 3 FOR X10.
C
      IFMT(1)=JFMT(4)
      IC=2
      IR=2
      IF (I.LE.9.AND.I.GE.-9) GO TO 117
      IR=3
      IFMT(1)=JFMT(7)
  117 CALL KANUM (XB,YB,HGTNUM,I,T,IFMT,IC,IR)
      GO TO 40
C
      END
```

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